THE ELECTRICAL EQUIPMENT OF COLLIERIES

W. G. DUNCAN & D. PENMAN.

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BY

W. GALLOWAY DUNCAN

ELECTRICAL AND MECHANICAL ENGINEER
LATE LECTURER IN ELECTRICAL AND MECHANICAL ENGINEERING, FIFE MINING CLASSES
MEMBER OF THE INSTITUTION OF MINING ENGINEERS; AUTHOR OF "HANDBOOK FOR ENGINEERING STUDENTS," "GUIDE TO THE ENGINEERING PROFESSION," ETC.
HEAD OF THE GOVERNMENT SCHOOL OF ENGINEERING, DACCA, INDIA

AND

DAVID PENMAN

CERTIFICATED COLLIERY MANAGER
LECTURER IN MINING TO FIFE COUNTY COMMITTEE
MEMBER OF THE INSTITUTION OF MINING ENGINEERS
PREMIER PRIZE-WINNER, "SCIENCE AND ART OF MINING," NATIONAL COMPETITIONS, 1906–7

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PREFACE

THE importance of electricity as applied to mines has been so fully established that the authors of this work have taken little trouble to argue the necessity for its installation in all cases where the circumstances permit or justify its use.

Prejudice played its usual part during the early period of the advent of electricity into the region of mining. Insufficiency of precautions against failure, or actual ignorance of essential requirements, did much to set abroad a spirit of antagonism, with the consequence that the development of electricity in its application to mining was greatly retarded. Even at the present time, when so many collieries have adopted electricity for haulage, pumping, coal-cutting, lighting, and other purposes, occasional accidents directly traceable to failure in one form or another of the electrical plant give rise to adverse comment and wholesale condemnation of the electric current as a suitable form of power for colliery work. It is to be feared that the true explanation of such events could be traced to insufficiency of knowledge on the part of men whose position requires of them a fuller understanding of the nature and possibilities of the power under their control. However, be this as it may, the fact remains that electricity is far and away the most efficient and economical form of power as yet within our reach for transmission down the mine.

Sometimes a statement is made to the effect that the installation of electric plant means considerable additional initial expenditure, which would be avoided were direct steam transmission adopted. This of course is undeniable, but then the ultimate saving in working cost, the economy in power transmission, the greater flexibility of the electric power in the diversity of uses to which it can be applied, will very soon more than repay the extra first cost. Besides, apart from any electrical consideration whatever, it is obvious that in a steam-driven generator set, supplying power to the whole mine or even to a group of mines, the engines can be worked at a considerably

lower cost per horse-power hour than can a number of smaller steam plants working independently, and operating different gears direct. In the first case, the most modern type of engine may be employed, while, in the second case, that would probably be impracticable owing to the smallness of the power required.

In consequence of the vast and ever-increasing growth of electric power in mines, it is absolutely imperative that not only the colliery manager, the mining student, and the colliery electrician, but everyone who at any time has occasion to come into contact with electrical apparatus of any description, should possess a clear grasp of the fundamental principles underlying the generation, transmission and utilisation of the electric current. Apart, however, from the purely scientific aspect of the subject, there remains, in the application of electricity to mining operations, numerous problems which call for special consideration, and which in themselves form a study, all-important to the student of mining.

Having regard, therefore, to this twofold aspect of the subject, the authors of the present treatise have devoted their attention, firstly, to the inclusion of sufficient electrical teaching as may be presumed to be necessary for the training of a thoroughly practical and competent manager of a colliery; and secondly, to the description of every application of electric power to mining that has yet been successfully attempted.

In a work of this nature, in which the knowledge of the electrician must be linked to the experience of the mine manager, it will be readily granted that joint authorship is very desirable, if not altogether essential.

Throughout this book the special requirements of the student have been recognised. A feature of the book is the tables of cost and productive results, which are given in a special chapter and elsewhere. That the book will prove of use to those for whom it has been designed is the authors' earnest wish.

W. GALLOWAY DUNCAN.
DAVID PENMAN.

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Our thanks are due the following for information given in their writings: Davidge and Hutcheson, Maycock, Ayrton, Ripper, Dawson, and others. To those firms who kindly supplied information and illustrations of their specialities, and to the Editor of *Science and Art of Mining* for permission to reprint portions of certain articles written by one of the authors, we are deeply indebted.

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ELECTRICAL EQUIPMENT OF COLLIERIES

CHAPTER I

GENERAL PRINCIPLES, MAGNETISM, UNITS, CELLS, ETC.

Introductory—Production of electricity by chemical action—Magnetism—Lines of magnetic force—Electro-magnetism—Conductors and insulators—Units of measurement—Volt—Ampere—Ohm—Coulomb—Farad—Joule—Watt—Henry—Board of Trade unit—Derived units—Primary cells—Leclanché—Carporous—Dry cells—Obach—Accumulators: E.P.S., Hart, Headland, Chloride, Edison—Efficiency of accumulators—Charging and maintenance.

THE subject of electricity forms a very profitable and fascinating study, and if properly handled may be made more interesting than the finest romance. The mysterious building up of an electric current through the mere revolving of a mass of insulated conductors in the heart of a magnetic field, the little less marvellous passage of the current so generated through suitable mediums to the motor, and the subsequent conversion of the electrical energy to mechanical power on the motor shaft, is all so subtle and so wonderful that the interest of the student cannot fail to be awakened and seized with an irresistible desire to learn the why and the wherefore of this astounding cycle of change.

Up to within little more than a quarter of a century ago the application of this wonderful agent to the various essential operations in mining was very limited indeed. Gradually, however, the vast possibilities of the electric current came to be recognised, and each succeeding year saw a steady growth in the variety of purposes to which it has been successfully applied. As is outlined in the Preface, it is our primary aim and purpose to give an account of the extent to which electricity has been introduced into the operations of modern

mining, and to demonstrate its superiority over other forms of power for transmission underground.

First of all, however, it will be necessary for us to acquire a clear grasp of the principles underlying the generation of electrical energy, the properties possessed by it, the methods of measuring, controlling, and utilising the current, and the various apparatus and appliances re quired, ere we attempt to deal with the application of the power to the doing of useful work.

We are all more or less familiar with the term "electricity." To some it represents some vague, unexplainable force, fraught with secret perils that terrorise the untaught mind; to others, more conversant with its real character and worth, it bespeaks a source of energy and power mighty in its ability to aid and abet mankind in the many phases of life which absorb and engross his ceaseless activities.

What electricity really is, no one has, up to the present, been able to clearly define.

Certain it is, however, that it is a force which man, as the fruit of his untiring genius, has been able to harness and utilise towards the fulfilment of his aims and purposes.

There have been two principal theories set up as explaining the nature and characteristics of the electric current.

The first is known as the "fluid" theory, which likens an electric charge to a fluid which, when subjected to pressure from a certain point, will flow in a direction opposite to that from which the pressure is applied. In this connection there is certainly a remarkable similarity between a fluid and a current of electricity. If we provide a suitable medium or circuit, as we generally call it, and increase the potential at one point of the circuit above the potential at another point, or in other words apply pressure to the charge, we shall cause a flow of electricity from the higher potential to the lower.

From this it will be seen that the "fluid" theory exhibits at least one characteristic justifying the use of the term. With this solitary instance, however, the analogy may be said to end. Although an electric charge will be found to exist at any point throughout its entire circuit, we cannot definitely say that the current actually *flows* from one point to another.

Again, electricity is intangible, imperceptible, and altogether void of weight, attributes which cannot be said to be possessed by any fluid known to us.

For these reasons, the "fluid" theory has now been discarded in favour of the second or "molecular" theory.

This theory declares an electric charge to be due to a certain undefinable state of the molecules forming the surface of the electrical conductor, and that both electricity and magnetism result from molecular motion.

For all practical purposes, however, it will be sufficient for us

that we continue to use those terms and expressions which have been associated with the science and art of electricity from the beginning, and which undoubtedly facilitate a readier acquaintance with the subject.

Throughout this treatise, therefore, whenever it is required to express the idea of electricity being transmitted from one point to another, such expressions as "flow of current," "passage of the current," "direction of flow," etc., will be found frequently quoted.

We derive the name "electricity" from the Greek word *Electron*, which means amber, because this substance if rubbed produces electricity.

Electricity has been stated to be a mode of motion in the minute atoms or molecules which constitute matter. It is not certain whether this motion is rotary or undulatory, but when compared with similar phenomena in sound, light, and heat it is probable that it is undulatory.

Electricity may be generated in many ways. Let us consider

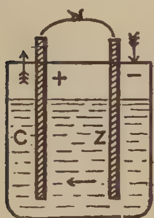


FIG. 1.

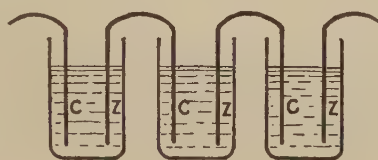


FIG. 2.

its generation by chemical action. A glass jar containing dilute sulphuric acid (H_2SO_4) has a zinc (Z) and a copper (C) plate immersed in the liquid. A copper wire is connected to the top of each plate. If these wires are brought together as shown in Fig. 1, a current of positive electricity is generated, which passes from the zinc plate through the solution to the copper plate, then it travels up the copper plate, through the wires to the zinc plate from which the current originally started. At the same time a current of negative electricity starts from the part of the copper plate which is in contact with the solution and travels in the opposite direction through the solution to the zinc plate, and then through the wire to the copper plate. If we connect up a number of these galvanic cells in series as shown in Fig. 2, *i.e.* the copper plate of one cell to the zinc plate of the other, and so on until all the cells are connected up, then on bringing the remaining wire from the copper plate to the remaining wire of the zinc plate a spark is obtained. If we connect a piece of thin iron wire with the ends of this battery of cells, we observe the iron wire is raised to a bright red or white heat, depend-

ing on the strength of the current. We see, therefore, that heat is produced, and infer that motion of one kind or another is going on in the battery and wires. Let us take an analogy. A train passes along a railway; the temperature of the rails is increased by friction with the wheels. The higher the speed of the train the greater will be the heat produced. We imagine motion to take place in the wire connecting the ends of the battery, and the quicker this motion the more heat is produced. We call this motion the electric current. According to Sulzer, if we place a zinc coin on the tongue of a person and a silver coin underneath the tongue, and bring the edges of the coins in contact, a peculiar salty taste is produced. If in a dark room, we place the zinc under the tongue, and the silver in the right place between the gum and cheek, and if the nervous system is at all sensitive, a feeble light will be emitted. These are the effects of electricity generated on the same principle as that described above as occurring in the glass jar.

Magnetism

A magnet is a body usually made of iron or steel, which has the property of attracting iron and other magnetic bodies. Magnets possess north and south poles. If similar poles of two magnets are brought together they repel each other, while two dissimilar poles attract each other. There are two kinds of magnets; permanent and temporary.

Loadstone is a substance found in nature which possesses the properties of magnetism. It is a compound of iron, and exists in Sweden, Norway, and in some parts of America. Its specific gravity is four and a half times that of water. It is reported that Sir Isaac Newton had a small natural loadstone magnet, weighing about three grains. It was set and mounted in a ring which he wore, and was capable of lifting about 250 times its own weight.

Bar magnets, if made of steel, are permanent magnets; they begin to lose their magnetism soon after the magnetising power is withdrawn. The electro-magnet is called a temporary magnet, because, as we shall shortly see, it loses its magnetism immediately the magnetising current is switched off. A bar magnet, if bent into the shape of a horseshoe, possesses greater portative power than if allowed to remain in the bar shape. In fact, it supports about twice the weight, because both poles act inductively on the keeper or weight to be lifted.

Lines of Magnetic Force

Take a piece of magnetised steel, either in the form of a bar or horseshoe, and lay a sheet of paper over it. Sprinkle soft iron filings on the paper, and you will at once perceive that the iron

particles arrange themselves in curves as shown in Fig. 3. The curved lines are called lines of magnetic force. Each particle of iron becomes a magnet by *induction*, with its north-seeking pole towards the south-seeking pole of the neighbouring particle, and *vice versâ*. A different arrangement is obtained by bringing two similar poles together. The lines in this case tend to go in the reverse direction. You must not believe in the positive existence of lines of magnetic force any more than in the actual existence of lines of latitude and longitude on the surface of the globe. Both are abstract conceptions, and are merely adopted by scientists for the purpose of measurement. A line of magnetic force is "that line which a very small needle describes when it is so moved, in any direction correspondent to its length, that the needle is constantly a *tangent* to the *line of motion*,"—or as "that line along which, if a *transverse* wire be moved in either direction, there is *no* tendency towards the *formation of any current* in the wire, whilst if moved in any other direction there *is* such tendency" (Faraday).

FIG. 3.

ELECTRO-MAGNETISM

If we take a rod of soft iron and coil or wind wire round it, and connect the ends of the wire to a source of electricity such as a battery or dynamo, we find that the rod becomes magnetic. If we break the contact, the magnetism disappears. Some of the energy of the electric current is transformed into its magnetic form, and, as in the case of the permanent magnet, we have a magnetic field, by means of which we may produce rotation and do useful work. If we take a bobbin which has been wound with wire, and allow a current to flow through the wire, we find the interior or hole in the bobbin to be a strong magnetic field. If we hold an iron rod near this aperture we find it is strongly attracted, and tends to be drawn into the hole.

CONDUCTORS AND INSULATORS

Substances are classified according to their power of conduction. The metals come first, offering as they do very little resistance to the passage of electricity. The resistance to the flow of electricity increases as we descend the table. The bodies increase in resistance and decrease in conduction, *i.e.* they become better insulators and worse conductors.

Good Conductors.—Silver, copper, gold, aluminium, zinc, brass,

iron, nickel, tin, lead, german silver, platinum silver, platinoid, antimony, manganin, bismuth, charcoal, carbon.

Bad or poor Conductors.—Salt water, damp earth, human body, flame, cotton, jute, linen, wood (dry).

Non-Conductors or Insulators.—Marble, slate, porcelain and china, oil, leather (dry), paper (dry), wool, silk, sealing-wax, sulphur, resin, water (perfectly pure), gutta-percha, ebonite, shellac, mica, amber, glass, air (dry).

Units of Measurement

Electricity is measured in well-defined and accurately determined units. The Volt is the unit of electrical pressure which, if applied to a conductor whose resistance is 1 Ohm, will produce a current of 1 Ampere. The Ampere is the constant electric current which when passed through a particular solution of nitrate of silver in water deposits 0·001118 gramme per second (an ampere is the current given by an electromotive force (E.M.F.) of 1 volt through a resistance of 1 ohm).

The resistance of a substance is the reciprocal of its conductivity, and is measured in ohms. The Ohm is the resistance offered by a column of mercury at the temperature of melting ice, 14·4521 grammes in mass, of constant cross-section, and 106·3 centimetres long.

Electric Quantity

The Coulomb is the quantity of electricity that flows per second past a given point which is carrying a current of 1 ampere.

Electrical Capacity

The Farad is the capacity of a condenser which would require a charge of 1 coulomb to produce a difference of potential of 1 volt between two conductors forming the condenser.

Electric Energy or Work

The Joule (Ayrton).—When a power of 1 watt is being developed, the work done per second is sometimes called a joule. Hence 1 joule = 0·7375 ft.-lb. and

1 watt second = 1 joule.
1 watt minute = 60 joules.
1 horse-power hour = 1,980,000 ft.-lbs.
1 horse-power hour = 2,685,606 joules.

Electric Power

The Watt (Ayrton).—A watt is the power developed in a circuit when 1 ampere flows through it, and when the potential difference at its terminals is 1 volt; hence the number of watts developed in any circuit equals the product of the current in amperes flowing through it into the potential difference at its terminals in volts. Therefore—

1 watt is the power developed when 44·25 ft.-lbs. of work are done per minute.

1 watt is the power developed when 0·7375 ft.-lb. of work are done per second.

1 watt $= \frac{1}{746}$th of a horse-power, and 746 watts = 1 E.H.P.

1 kilowatt $= \frac{1000}{746} = 1{\cdot}34$ horse-power.

Electrical Inductance or Self-Induction

The Henry.—The induction in a circuit when the difference of electrical pressure induced in the circuit is 1 volt, while the inducing current varies at the rate of 1 ampere per second, is called a Henry. It corresponds to a rate of change of magnetic field strength through the circuit.

The Board of Trade Unit

For commercial purposes electrical energy is charged for in units of 1000 watt-hours each. This unit is called the Board of Trade unit.

1 Board of Trade unit $= \frac{1000}{746} = 1\frac{1}{3}$ horse-power hour (approx.).

Derived Units

1 megohm = 1 million ohms.
1 microhm = 1 millionth of an ohm.
1 milliampere = 1 thousandth of an ampere.
1 microfarad = 1 millionth of a farad.
1 millivolt = 1 thousandth of a volt.
1 kilowatt = 1000 watts = 44·240 ft.-lbs. per min. = 1·34 H.P.
1 electrical horse-power = 746 watt hrs. = 33,000 ft.-lbs. per min.
1 joule = 1 watt sec. = 0·7373 ft.-lb.
1 foot-lb. = 1·356 joules.
1 B.T.U. = 3,600,000 watt sec.
1 kilogramme metre = 7·233 ft.-lbs.
1 kilowatt hour = 1·34 horse-power hrs.

1 French or metric horse-power = 75 kilogramme metres per sec. = 32,549 ft.-lbs. per min. = 736 watts = 0·9863 English horse-power.

1 English horse-power = 1·01385 French horse-power ("force de cheval").

Ohm's Law

It was found by Dr. Ohm after careful experiment that the quantity of current obtainable from any given electromotive force is equal to that electromotive force divided by the resistance, and so, if we know two quantities, the remaining quantity may be easily determined. Where E stands for electromotive force in volts, C for current in amperes, and R for resistance in ohms, we have :—

$$R = \frac{E}{C} = \text{ohms} = \frac{\text{volts}}{\text{amperes}}.$$

$$C = \frac{E}{R} = \text{amperes} = \frac{\text{volts}}{\text{ohms}}.$$

$$E = C \times R = \text{volts} = \text{amperes} \times \text{ohms}.$$

This is known as Ohm's law, and is of the utmost importance, but in the simple form given here it only holds good for continuous or direct current.

Examples in Ohm's law :—

1. A dynamo produces an E.M.F. of 210 volts, and the total resistance of the circuit, including dynamo, lamps, and mains, is 14 ohms. Find the current.

$$C = \frac{E}{R} = C = \frac{210}{14} = 15 \text{ amperes}.$$

2. An accumulator battery has an E.M.F. of 50 volts, and sends a current of 25 amperes through an external circuit. Find the resistance of the circuit.

$$R = \frac{E}{C} = R = \frac{50}{25} = 2 \text{ ohms}.$$

3. A battery of cells having an internal resistance of 0·55 ohm sends a current of 10 amperes through a circuit, the resistance of which is 1·05 ohm. Find the E.M.F. of the battery of cells.

$$E = C \times R = (0{\cdot}55 + 1{\cdot}05) = 1{\cdot}6 \times 10 = 16 \text{ volts}.$$

An electric current may be generated by means of the primary cell or battery. Let us consider the most important types of this form of generator.

Primary Cells

Leclanché's Cell.—This is, perhaps, the most popular type of primary cell, and is widely used for telephone and bell circuits. The

outer glass vessel contains a cylindrical porous pot. The function of this porous pot is to act as a support for the solid particles which surround the carbon plate. This carbon plate or block is put into the porous pot, and the intervening space tightly packed with equal proportions of small pieces of carbon and manganese dioxide. The top of the porous pot is capped with pitch, and the protruding carbon plate is fitted with a terminal. Two short pieces of ebonite tubing admit of the free passage of gas from the inside of the pot to the air, and also enables some of the solution to be poured into the porous pot. The outer glass vessel is half filled with a strong solution of sal-ammoniac (ammonium chloride). A pure zinc rod with a connecting wire soldered to it is inserted in the solution. The top part of the outer vessel is dipped in a black compound, thus preventing the solution from creeping from the inside to the outside of the vessel.

When a current is flowing, ammonia gas is given off, and zinc chloride and water are formed. The internal resistance varies from 1 to 3 ohms, dependent upon size of carbon plate and zinc rod and the distance separating them. The E.M.F. of Leclanché's cell is about 1·8 volt.

Casin gives the following table :—

POROUS POT

Size.	Diameter.	Height.	Resistance.
1	2·4 ins.	4·4 ins.	9 to 10 ohms.
2	2·4 ins.	6·0 ins.	5 to 6 ohms.
3	3·25 ins.	6·0 ins.	About 4 ohms.

The "Carporous" Cell is a modified form of Leclanché, consisting of an outer glass vessel (Fig. 4, G) containing a solution of sal-ammoniac. An outer perforated cylinder of carbon (R) enclosing a cylinder of porous porcelain (O), both resting on a glass base (C), perform the function of the porous pot in the ordinary type of Leclanché. In the space between these two cylinders a mixture of carbon and manganese dioxide is packed (P). The zinc rod (Z) passes through an insulating top into the inside porous porcelain cylinder, and into the solution which finds its way into the inside cylinder. Terminals fixed to the carbon cylinder and zinc rod convey the current to the external circuit.

Dry Cells

The name implies that no liquid is used. A jelly paste takes the place of the liquid, by which the same action takes place as in a liquid cell.

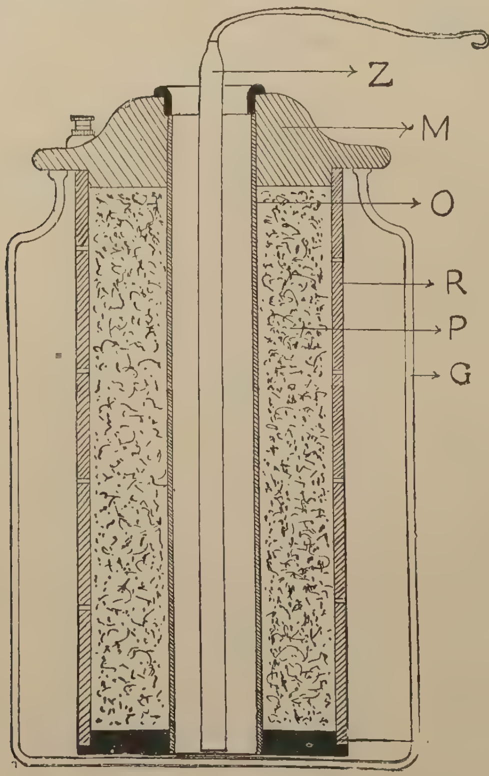


Fig. 4.—Carporous cell.

The Obach Cell.—In this cell the zinc forms the outer vessel, and is fixed to an insulating base. A carbon rod is placed in the centre of the cell, and is surrounded by a mixture of manganese dioxide and plumbago in equal proportions, made pasty by the application of a little gum tragacinth. The electrolyte consists of 85 per cent. of plaster of Paris and flour mixed to a paste with sal-ammoniac solution. The top is made with ground cork, and is covered with an insulating cap. A small vent hole permits of the escape of gases liberated by the action of the cell. Ter-

minals are fixed to the zinc and carbon to allow of the current being taken away. The E.P.S., Dania, Argyll, Edison, and G.E.C. (Fig. 5) are types of dry cells much the same as regards construction. These cells may be used in any position and for a variety of purposes, such as shot-firing in mines, telephones, bells, indicators. The E.M.F. averages about 1·5 volt, and the internal resistance varies from 0·5 to 3 ohms.

Accumulators

The great drawback in the primary cell is its rapid polarisation when a steady current is required of it. But, as the result of experiments made by Ritter and Planté, we now have cells in which the energy of chemical change can be stored in the cell and used in the form of electric current to do useful work. Such are called Accumulators or Secondary Cells. It must not be supposed that the electricity is stored or accumulated in the form of current, but rather that a chemical change takes place between two constituents which causes the electricity to flow. If a current is passed through water or other decomposable liquid, the electrodes being made of platinum, a current is found to flow when the charging battery has been removed. This is due to the reverse E.M.F. produced by hydrogen and oxygen gases in the platinum plates. This is the principle of Grove's gas battery, and was one of the earliest forms of secondary cells produced. Gaston Planté substituted lead plates for platinum plates. These lead plates were immersed in dilute sulphuric acid. On connecting the plates to the charging current electrolysis takes place, hydrogen escaping at the cathode (+), while oxygen combines with the anode (−), and forms lead peroxide. If the charging current be continued, and the plates reversed periodically, spongy lead will be found on one plate and peroxide on the other. This process of reversal is called "forming." When discharging, the spongy lead and peroxide are converted into lead sulphate. This "forming" process may be accelerated by pasting the plate with red oxide of lead. Numerous devices and improvements have been made in the construction of secondary cells so that the efficiency, durability, and capacity may be increased. The lead plates are now cast in the form of grids, the intervening spaces being filled with oxide. There are different forms of cells in use at the present time, most of them based upon the principle of Planté. It may suffice to mention two or three of the leading types.

Fig. 5.—G.E.C. dry cell.

The E.P.S. Accumulator.—The positive plates have narrow inclined shelves running horizontally, and a paste made of red lead and sulphuric acid pressed on to these shelves. The negative grid before pasting has a fantastic pattern. Little claws project out from the square apertures of which the plate or grid is composed. A paste composed of powdered litharge and sulphuric acid is held in position by these claws. The plates, after drying, are immersed in dilute sulphuric acid having a specific gravity of 1·19, and "forming" takes place by passing a current from the positive grid through the liquid to the negative grid—peroxide being formed on the positive

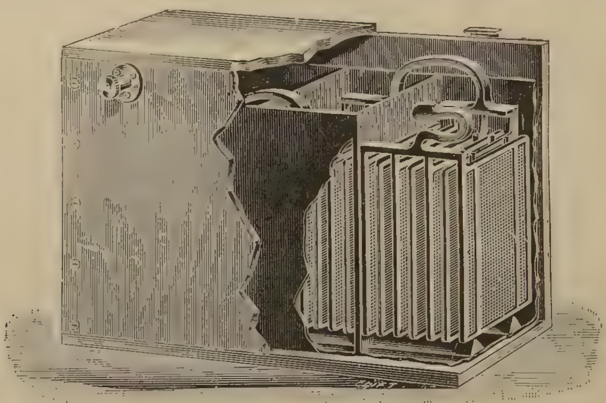


FIG. 6.—E.P.S. accumulator.

grid and spongy lead on the negative. The "forming" process is not yet complete, but goes on for four or five days with a weak charging current. The charge is then increased until the maximum charging rate is reached. Fig. 6 shows a portable form of E.P.S. accumulator. L. type is adapted for electric light installations, where the discharge is of long duration; K. and W.S. types are used chiefly for telegraphic purposes.

Hart Accumulator.—The positive and negative plates or grids are similar in design. Both have horizontal ribs rolled and turned up at the edges, so that the active material may be securely held together. These ribs are connected to vertical ribs, and by fastening together to a solid diaphragm the plates are given greater strength to withstand buckling. The negative plate is without the diaphragm. The waste material falling from the plates during charging and discharging accumulates in the bottom of the cell, so that clear space must be provided. In the Hart cell this is done by supporting the plates on wood blocks in the bottom of the cell, and

E.P.S. Secondary Cells

also by means of lugs cast on one set of plates. Each plate is insulated from its neighbour by a glass tube with three flanges. Non-corrosive terminals with tapered bolts are used for connecting up the cells. The whole connection is cast from an alloy which is not readily affected by the fumes from the acid.

No. of Plates.	Charge in Amperes.	Discharge in Amperes.	Capacity in Ampere Hours.		Dimensions.	Weight.
					ins.	lbs.
L. 7	10 to 13	1 to 13	130		$5\times13\times14\frac{1}{2}$	71
L. 33	54 ,, 64	1 ,, 64	704		$20\times13\times14\frac{1}{2}$	310
K. 33	66 ,, 135	1 ,, 135	448		$9\frac{3}{8}\times11\frac{3}{8}\times13\frac{1}{2}$	348
		Discharge.				
W.S. 25	67 to 135	2 hrs. 180	$3\frac{1}{2}$ hrs. 144	7 hrs. 90	$20\frac{1}{4}\times13\times14\frac{1}{2}$	375
P. 25	300	1 hr. 600	$3\frac{1}{2}$ hrs. 300	7 hrs. 180	$18\frac{1}{4}\times25\times22$	890

The Headland Accumulator.—The grids in this cell are made up of bar sections. These bars are skeleton-shaped when cast, and the spaces filled with active material. They are placed side by side to form the plate, the number of bars determining the size of the plate. The space between the plates is kept constant by means of corrugated ebonite sheets or glass rods.

The Chloride Accumulator.—The positive plates are made from an alloy of lead and antimony, and have holes cast in them. Pure lead tape made into cores is pressed into these holes, and the plate is then pressed by hydraulic means to a pressure of 75 tons to the square inch. A current is then passed through them in a voltameter, and lead peroxide, due to the hydrogen which is liberated, is formed on the plate. The negative plate is made in a different manner. Lead acetate when treated with hydrochloric acid forms lead chloride, and this is moulded into cakes and dried by heating. The lead chloride along with powdered zinc is made molten and cast into hexagons. These are "placed" in a mould, and molten lead under pressure forced around them, the result being a perfectly compact plate. The small hexagons are reduced to spongy lead by the plate being inserted in a vessel containing zinc chloride and zinc plate.

After washing, the plate is placed in a voltameter which removes any chloride still present. The plates are then fitted up in the cell in the usual way.

The Edison Accumulator.—This cell is made up of two thin steel frames, fitted with perforated pockets or boxes also made of steel. These pockets are fitted with nickel oxide for the positive frame of plate, and iron oxide for the negative frame. The solution is made from caustic potash. When the charging current is switched on, the nickel oxide in the pockets of the positive plate is converted into nickel peroxide, and the iron oxide in the pockets of the negative plate is reduced to metallic iron. When current is taken from the battery the nickel peroxide and the iron become oxidised. From tests made with this cell it is found to give 1·35 volt. A cell with a normal discharge rate of 30 to 40 amperes gives 80 per cent. of its normal ampere-hours, with a 200-ampere discharging current. The efficiency of this cell is much lower than the ordinary lead plate accumulator, but its advantage is that it will stand more rough usage, and is less liable to get out of order. Experiments have shown that if it is short-circuited for two days it will recover its original capacity after a couple of charges, and apparently be none the worse. The charging current may be made four times the original amount without ill effects. The cell may be left without charging for a considerable period. As this cell is in its infancy yet, it is hardly possible to predict what the future may have in store for it.

In the Edison accumulator the number of negative plates exceed the positive by one. This arises from the fact that the positive plates must be acted upon from both sides at once, or they tend to "buckle."

Efficiency of Accumulators

The current obtainable from a secondary cell depends upon the total area of the positive plates. By having a positive plate, say, equal in size to four plates of an ordinary accumulator, the same result may be obtained, but it is more convenient to have four plates of a suitable size, as there is less risk from buckling, and they are more easily handled, and take up less space. The energy of the cell = watts × time in hours = watt-hours.

Therefore we have

$$\text{Efficiency} = \frac{\text{energy given out}}{\text{energy put in}}.$$

In practice this varies from 55 to 75 per cent.

Secondary cells or accumulators find their field of usefulness in supplying steady current for lighting or power where it is inconvenient to have the generator always running, and also to help the generators to cope with the load at its highest peak or maximum load.

Charging and Maintenance of Accumulators

Some practical hints on the charging and maintenance of accumulators may not be out of place here.

The battery house should be well ventilated, to allow of the escape of acid fumes. A brick or stone building is preferable to wood. Any metal connections and fittings should be coated with creosote or vaseline, as the acid fumes attack metal quickly. Plenty of room should be provided around the tiers so that inspection and attention may be carried on with facility. Care should be taken to see that no plates are buckled; if found so, they should be taken out and straightened. When a positive and negative plate are short-circuited, this cell should be disconnected at once and the fault remedied. The specific gravity of the liquid should be noted from time to time, and a testing voltmeter placed across the terminals of

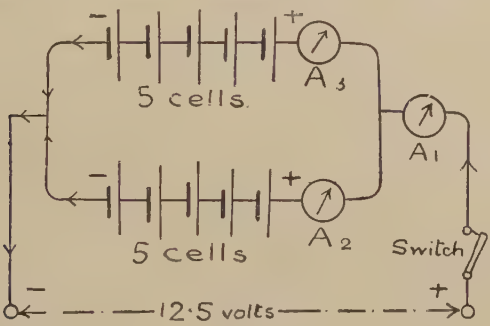


Fig. 7.

each cell. The reading should be the same for each cell when discharging. Thorough insulation in a battery of cells is essential. The glass cell rests on a wooden tray filled with sawdust. The tray rests upon oil insulators made of glass. The insulator consists of two parts, the lower part having an annular channel in which a non-evaporating oil is placed. The rim of the top part fits into the channel, so that leakage current meets with a very high resistance in the oil moat. When installing a new battery, all the charging arrangements should be ready before any acid is filled into the cells; otherwise a coating of lead sulphate will be formed, and the efficiency of the cell lowered. The acid should have a specific gravity of 1·19, and be free from sediment. The plates should be covered to the extent of about half an inch. Compensation should be made by adding water when the electrolyte evaporates. Glass sheets are usually placed over the plates to arrest spraying. The generator for charging must be shunt-wound or separately excited. If a compound-

wound dynamo is used, the series coil should be cut out. The voltage should be 2·5 volts per cell. The first charge should extend from 10 to 35 hours, and the current should not be taken from the battery until the evolution of gas takes place at the plates and the electrolyte assumes a milky colour, while the acid should have a specific gravity of 1·205. When finished charging the battery, the switch should be immediately turned off, and this must take place before the generator has stopped, else the current from the cells may drive the dynamo as a motor, and permanent damage result. When the E.M.F. of the cells falls below 1·8 volt, and the specific gravity of the acid 1·18, they should be recharged, or the plates will become

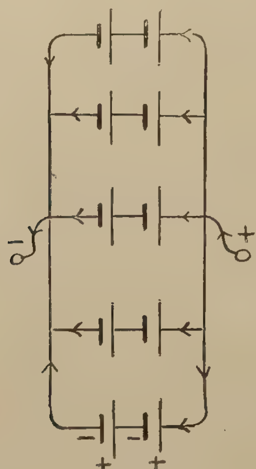


FIG. 8.

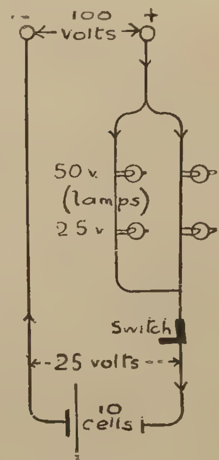


FIG. 8A.

sulphated. In order to obtain the best results from accumulators they should be kept well, and even although current is not being taken from them, a charge should be administered weekly.

Fig. 7 shows how to connect up two accumulator batteries, each comprising five cells for charging in parallel. The voltage used is 12·5 volts, and this gives a potential of 10 volts in each battery.

Fig. 8 illustrates diagrammatically the connections for charging 10 cells, in five sets, in parallel.

Fig. 8A shows how to connect up a 10-cell battery for charging from a 100-volt circuit. The lamps are put in to take up the extra pressure.[1]

[1] We are indebted to Percival Marshall & Co. for the loan of Figs. 7, 8, and 8A, as well as Fig. 4.

CHAPTER II

DYNAMOS AND MOTORS

Principle of the Dynamo—Continuous current dynamos—Series, shunt, and compound-wound—The alternating current—Period—Frequency—Amplitude—Lag and lead—Phase difference—Single-phase generator—Two-phase generator—Three-phase generator—Electro-motors—Direct current electromotors—Back E.M.F.—Types of motors—Alternating current electromotors—Motors for coal-cutting machines—Motors for haulage and pumping—Motor-generator—Static transformers—Rotary converters—Care of electrical plant—Earthing of dynamos and motors—Coupling dynamos together.

THE production of electricity by chemical action is a most expensive process, and, except for signalling and telephone circuits, the generation of the electric current by this means cannot be entertained. For the generation of electricity for power and lighting purposes the electric machine known as the dynamo is employed. This machine, although possessing the ability to generate an electric current, is dependent upon an outside source for one of the two elements which, working in unison, result in the building up of the electric current.

It is for this reason that electricity as generated in the dynamo can only be classified as a secondary power.

The two fundamental principles which underlie the production of electricity in the dynamo are magnetism and motion. If we have a magnet, and rotate or revolve a coil or coils of copper wire between the north and south poles of the magnet, we will obtain a current or flow of electricity in the coil of wire. Grasping this fact at the outset, the student will readily understand the action of any type of electric generator.

To further illustrate the principle underlying the action of the dynamo, the sketch in Fig. 9 is given.

CONTINUOUS CURRENT DYNAMOS

In order to produce an electric current sufficient for practical purposes, we must have a powerful magnetic field, and a set of coils to cut the lines of magnetic force in that field, also gear for collecting

the current so that it may be distributed to the various places where power and light are required. This appliance or machine, as we have already stated, is called the dynamo or generator. The stationary electro-magnets producing the field are called field magnets, the revolving coils cutting the field being termed the armature. When dynamos were first constructed, permanent magnets were used, but now the magnetism is produced electrically, the exciting current being shunted from the dynamo itself. The field magnets may be two, three, four, six, eight, or more in number. When more than

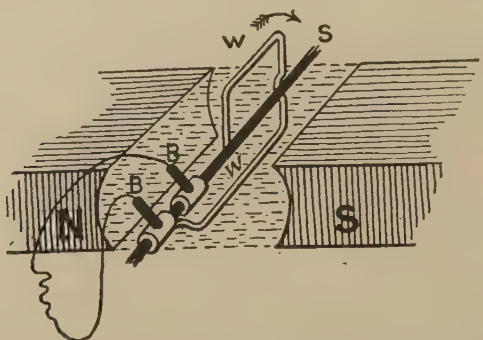


Fig. 9.—A single loop of wire WW is rotated by the spindle S between the N and S poles of a magnet. The brushes BB collect the current. The external circuit is shown connected to the brushes. The lines of magnetic force between the poles are shown by the dotted lines. A current is induced in the coil when it is revolved between the N and S magnet poles, and cuts the lines of force. The current generated flows from one brush through the external circuit to the other.

two poles are used, the machine is termed a multipolar generator. The exciting and winding of the field magnets may be performed in three different ways, classified as follows :—

Series-wound, Shunt-wound, and Compound-wound

The *Series-wound Machine* (Fig. 10) is so called because the field magnet coils, armature, and external circuit are all connected in series. The windings consist of a few turns of thick insulated wire having a low resistance. Series-wound machines were formerly much in use for arc lamp lighting, but have been supplanted by shunt-wound machines.

The *Shunt-wound Machine* (Fig. 11).—In this type the field magnet coils are connected as a shunt across the brushes ; the current

generated in the armature may flow through the magnet coils or through the external circuit to lamps, motors, etc. As the voltage remains constant, this type of machine is used for parallel circuits requiring a constant voltage and varying current; for example, incandescent and arc lamps, motors, etc.

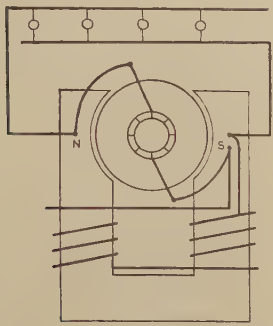


Fig. 10.—Series-wound dynamo.

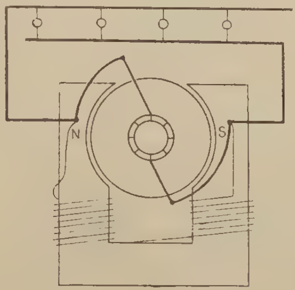


Fig. 11.—Shunt-wound dynamo.

The *Compound-wound Machine* (Fig. 12) is a combination of the series and shunt-wound types. The field magnets are shunt-wound with a few series turns, so that both windings help to magnetise the poles. The advantage derived from compounding is that a constant

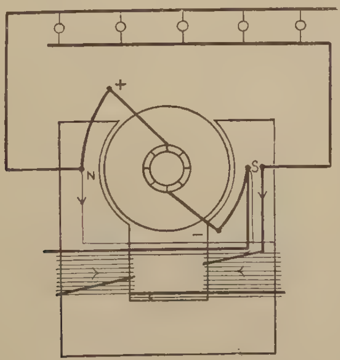


Fig. 12.—Compound-wound dynamo.

terminal voltage is secured, even although a varying current be taken. The voltage rises with the current in a series-wound machine. When the current consumpt is increased in a shunt machine, then the pressure falls. It is obvious, therefore, that by a combination of

the two a constant pressure at all points of the load or current consumpt is secured, as in the compound-wound machine.

Some machines are over-compounded, thereby securing a rise of voltage when the current is increased. This is obtained when additional series turns are wound on a compound-wound machine.

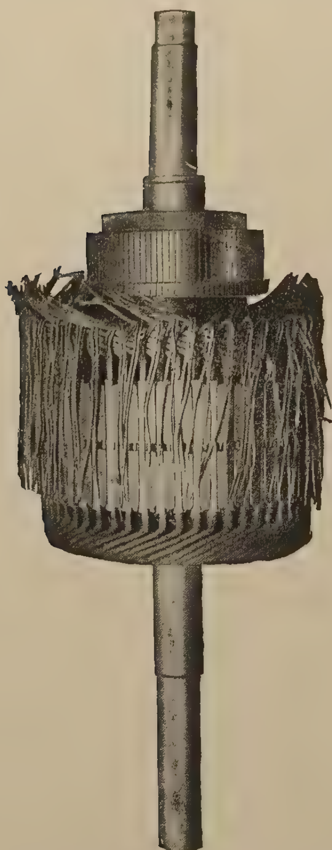


Fig. 13.—Armature partially wound.

Fig. 14.—Armature complete with commutator.

The advantage accruing from over-compounding is that the effect of voltage drop in a long circuit may be done away with. For example, when we desire a constant voltage at the place where the current is being used, instead of at the dynamo terminals.

Short and Long Shunt are terms used to denote the different ways of connecting the field-magnet coils of a compound-wound machine.

The first, so called when the shunt coils are connected direct to the brushes. The second, when the shunt coils are connected to the armature and series coils combined.

These machines are now used to a large extent, particularly when the voltage is high, say 500 volts. The great advantage they possess is that the armature revolves at a fairly slow surface speed.

The winding for the magnet coils is usually done on formers, so that the coil intact may be slipped over the limb. Presspahn is used for insulation purposes. For machines of large output the shunt coil is composed of "formed" strips of copper insulated by tape. In the case of compound-wound machines the series winding of thick wire is wound on the outside of the field magnets, while the shunt winding of thin wire is below.

As already stated, the revolving part of the generator or dynamo is called the armature. It consists of a large number of slotted charcoal iron stampings or discs, and threaded on the spindle or shaft. The discs are held in position by an end plate or spider. Each stamping or disc is separated from its neighbour by a sheet of thin paper in order to prevent eddy currents. The armature windings, after being bent into position, are laid in the slots, and the ends are connected to projecting strips attached to each bar of the commutator (see Fig. 13). The commutator consists of a number of tapered copper bars assembled together by hydraulic pressure. Each bar is insulated from its neighbcur by thin pieces of mica, and has a connection to a corresponding winding or coil on the armature. Fig. 14 shows an armature complete. By means of brushes resting on the commutator, the current in the armature caused by its coils cutting the lines in the magnetic field is collected and delivered to the mains as a continuous current. For example, if we trace the circuit of any one winding beginning at a bar on the commutator, we note it passes along a slot in the drum of the armature and crosses the end of the stampings of which the drum is composed, thence along another slot in the reverse direction, and back again to another commutator bar. There are different ways of winding armatures, and especially drum armatures, but we cannot enter into these here. For the winding of armatures the reader is referred to text-books on Electrical Engineering. Fig. 15 shows a modern type of continuous current generator.

The efficiency of a dynamo may mean mechanical, commercial, or electrical efficiency. There are, and will always be, certain losses in machines. In the dynamo we have losses due to the frictional resistance of the shaft in its brasses, resistance of brushes pressing on commutator, air resistance, heating of armature and magnets, hysteresis, and eddy current losses.

The mechanical efficiency is defined by the ratio of the total watts generated divided by the supply of mechanical power; the

electrical efficiency, by the watts in the outside or external circuit divided by the total power supplied to dynamo. It is obvious, then, that the mechanical efficiency is equal to the commercial efficiency divided by the electrical efficiency.

The Alternating Current

The current derived from a simple cell is continuous, that is to say, it flows in one direction from the positive pole through the external

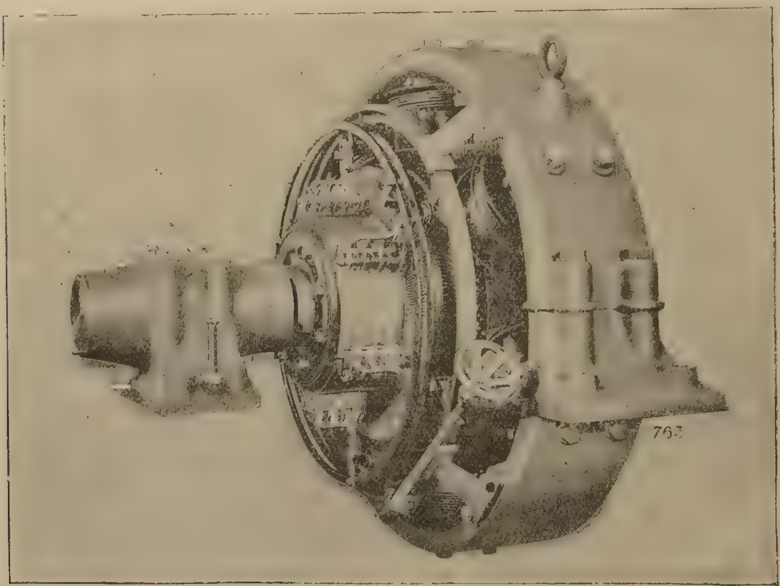


Fig. 15.—Continuous current generator for coupling to high-speed engine.

circuit, returning to the negative pole. There is, however, a current which does not flow continuously in one direction, but periodically reverses, flowing to and fro in an undulatory manner; such is termed an alternating current. The balance wheel of a watch is a very good example of the constant oscillation of an alternating current in a conductor. When we drive an alternating current through a circuit, the electromotive force constantly changes. At one point it will attain to a maximum, then fall away to zero; reversing, it reaches a maximum, and falls back again to zero. Two alternations or reversals are termed one cycle, and the time taken to complete one cycle is termed one period, and the number of periods performed in

one second is termed the frequency. Amplitude is a term given to the maximum value of the electromotive force. Frequencies between 25 and 40 cycles per second are common in practice, although alternators giving 100 cycles per second are in use.

In the curve shown in Fig. 16 time is represented along the horizontal axis XY, the electromotive force by the vertical line OP. The volts measured above the zero line may be called direct or "right hand," below the zero line, reversed or "left hand." The curve

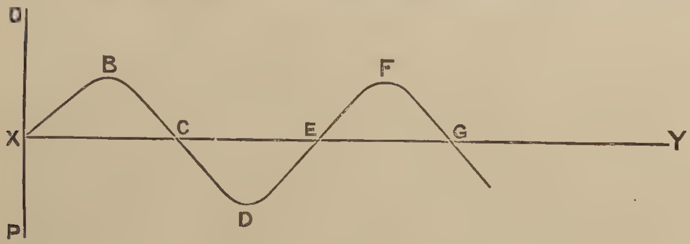


FIG. 16.

shows the variation of the electromotive force with the time. The distance from C to G is termed the period, and the frequency represents the number of such periods performed in one second. The maximum points BDF denote the amplitude. By selecting any point on the curve it is possible to obtain the value of the voltage at a given time by drawing a line parallel to the zero line.

It is a well-known fact in practice that alternating currents do not keep in step with the electromotive force, so that the maximum

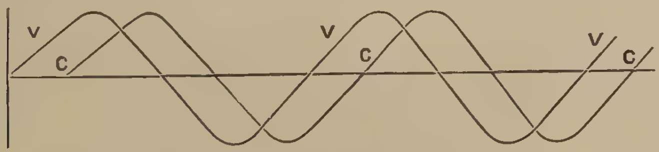


FIG. 17.

value of the current does not occur when the electromotive force is at its maximum. This difference of phase is termed "lag." In the reverse case, when the current occurs before the electromotive force, then the current is said to "lead." A glance at Fig. 17 shows the curve VVV representing the rise and fall of the electromotive force. The curve CCC is shown beginning its cycle later. This is due to induction. The angle which the current lags behind the electromotive force is usually denoted by ϕ. Now, where E equals the electromotive force in volts, and C the current in amperes, we may find the

rate of energy expended by multiplying the impressed volts by the effective amperes and the cosine of the angle ϕ (the value of the cosine of any angle may be obtained from tables). On dividing the product by 746 we get the energy expended. The harmonic motion of the curve, showing the variation of pressure and current, tends to assume

Fig. 18.—Stationary armature of Westinghouse rotating field alternating current generator.

the sine law, so that by using the sine curve we can obtain, mathematically, the pressure and the current curve.

In the generation of alternating currents, an alternating current dynamo is used, and is more generally known as an alternator. It is much easier to produce alternating current than continuous current. A dynamo in its simplest form produces alternating current, but by

introducing certain windings it is made to generate a current which is continuous. Unlike continuous current machines, in the modern type of alternating current generator, the armature remains stationary (see Fig. 18), while the field magnets revolve inside the armature ring (Fig. 19). The inductor type of alternator is perhaps the strongest and most reliable. The armature is stationary, and the magnetic field, consisting of soft iron blocks, cuts the lines of force

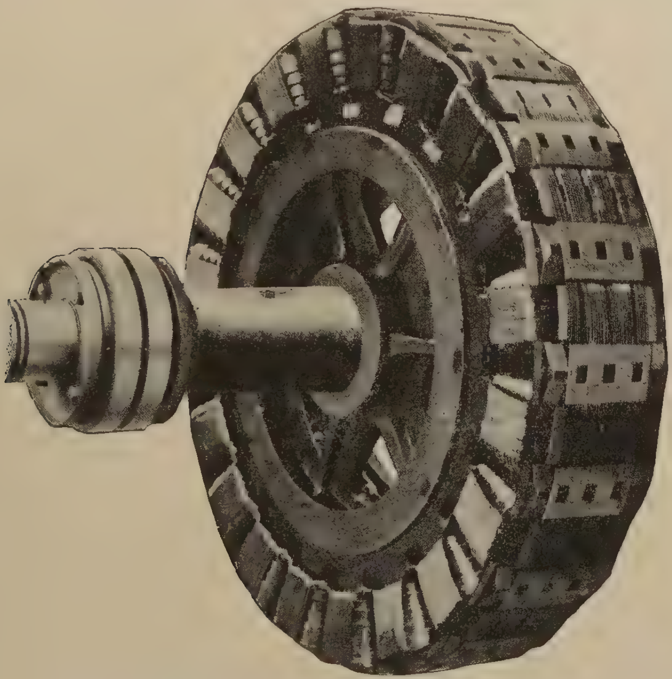


FIG. 19.—Rotating field of Westinghouse alternating current generator complete with coils and slip rings.

and induces current in the armature conductors. The chief features of this machine lies in the fact that no copper electrical conductors are in motion. For the exciting of the magnets for the magnetic field, small continuous current dynamos are used. These are usually placed beside the alternator. It is obvious that owing to the reversal of the intermittent current it cannot be used for exciting purposes. Fig. 20 shows a three-phase alternating current generator with exciter. The essential difference between the three types of alternating

current generators, namely, the single-phase, the two-phase, and the three-phase machines, may be briefly stated as follows :—

Single-phase Generator.—The stationary armature in this type of machine consists of a series of coils equal in number to the field magnets in the revolving part of the machine. The armature coils are connected up in series, the direction of winding being alternately reversed so as to enable a flow of current to be produced through the series of coils. The E.M.F. alternately rises and falls as the field magnets revolve. When the field magnets are exactly opposite the

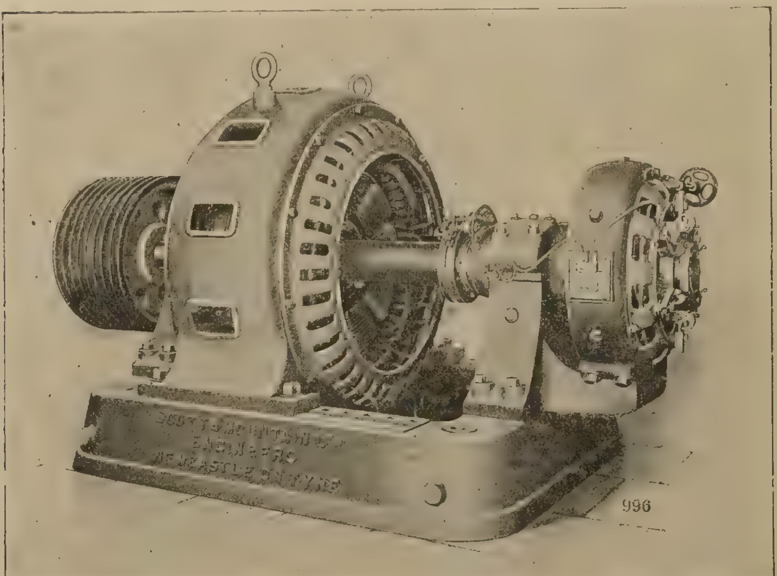


FIG. 20.—Three-phase alternating current generator, with exciter.

armature coils, the E.M.F. is at zero; and when the magnets are mid-way between the coils, they are cutting the maximum number of lines of force, and in consequence the E.M.F. is also maximum. The direction of flow of the current alternately reverses as each succeeding armature coil is crossed by the revolving field magnets. The number of alternations of the current per revolution will therefore equal the number of field poles, or, which is practically the same, the number of armature coils. The periodicity will be exactly half of this, as two alternations are equal to one period.

Two-phase Generator.—The two-phase machine differs from the single-phase generator in that the former type of machine has two

armature coils to every field-magnet pole. The coils are arranged in two rings, one behind the other. The coils in the second series bridge the gaps between the coils in the first ring, or, in other words, the coils in the second series are set half the angular length of a coil in advance of the coils in front. Through this arrangement of the armature coils the two-phase current is produced. The two-phase current may be likened to two separate single-phase alternating currents, one of which is at its maximum E.M.F. when the other is at zero, and *vice versâ*.

Three-phase Generator.—In the three-phase generator there are three separate sets of coils in the armature. Each coil is set two-thirds of the pitch of the field magnets in advance of the coil in front of it. To make this plainer, suppose one armature coil to be set in a certain position in the first set of conductors; then the corresponding coil of the second set of conductors would be arranged two-thirds of the pitch of the field magnets, or, in other words, two-thirds of the distance from the centre of one field magnet to the centre of the next, in advance. The coil in the third set of conductors is set two-thirds of the pitch in front of the coil in the second series. The distance from the beginning of the first coil in the first set to the beginning of the second coil in the same set is equivalent to a period, and embraces one coil in each set of conductors. The ends of the three sets of conductors are afterwards brought together. This arrangement of the armature coils enables three-phase current to be produced.

Electro-Motors

The transformation of electrical into mechanical energy is produced by means of the electric motor. Electric motors are extensively used in collieries and mines for the performing of useful work on the surface and underground. When electricity was first used in mines the system adopted was that of the direct current, but with the advent of polyphase alternating current and its attendant advantages, continuous current has been to some extent displaced in modern collieries. Let us look for a little at the advantages offered by the use of polyphase current. As no commutator or brush gear are required on polyphase motors, the danger arising from sparking is obviated. In a damp atmosphere it has been found that a polyphase motor is less liable to break down than one fed by direct current. This is due to the construction of this type of motor, also much less attention is needed with motors working on the alternating current system. Lastly, and perhaps the greatest benefit is that alternating current can be easily transformed for distribution to the various points of working, no matter how far distant. There are different types of motors for use in collieries. Some are totally enclosed, while in others the working parts are exposed.

Direct Current Electro-Motors

When the armature of a generator is supplied with current from an external source, the poles or field magnets become magnetised, causing the necessary flux to enable the armature to revolve. The electric motor is merely a dynamo, with the difference that instead of supplying current, current is supplied to it. If a conductor carrying a current is placed in a magnetic field, a force acts upon it at right angles to the field and the current. This force, if properly utilised, causes motion of the conductor. The direction of motion may be found by the left-hand rule. "Place the left hand across the conductor with the palm facing the conductor, and the thumb, forefinger, and other fingers stretched out at right angles. The forefinger must point in the positive direction along the field, and the other fingers in the direction of motion. Then the thumb will denote the direction of the induced current."

When a motor revolves it acts as a dynamo, generating a separate E.M.F. of its own, which acts in opposition to the incoming current. This is called the *back E.M.F.* of the motor. Now, a dynamo requires to be running some time before it can attain to its maximum E.M.F. The same thing applies to a motor. Therefore, if we start the motor at full speed, there being no *back E.M.F.* to resist the incoming current, there would be such a rush of current that the armature coils would be heated to a dangerous extent. In consequence of this a rheostatic switch has to be inserted in series in the armature circuit, so that the motor may be enabled to start slowly. This allows a *back E.M.F.* to be generated in the motor ere the resistance coils of the rheostat are cut out of the circuit.

Types of Motors

1. *Series-wound Motors.*—The chief point about this motor is that it is easy to start when the conditions demand a powerful starting torque.[1] As the load decreases the speed increases, and *vice versâ*. With a very light load the back E.M.F. rises, with the result that the magnetic poles lose their magnetism, thus causing the motor to race. Therefore it is obvious that series-wound motors must not be used in cases where the load is likely to be entirely removed. Where the load and speed are constant, such as in pumps and ventilators, and where the motor is required to run fast or slow, with increase or decrease of load, and when required to start up under a heavy load, for example, electric locomotive cranes and other heavy machinery,

[1] "Torque" is a word used to express the moment of a force about an axis. It is often expressed as the pull in lbs. exerted at the end of a lever one foot long. It may be more simply defined as the turning or twisting power of the armature. In the armature of an electro-motor it is proportional to the strength of the magnetic field and the current in the armature.

series-wound motors are most suitable. A practical example of the series-wound motor may be found in driving pumps in mines.

2. *Shunt-wound Motors.*—In this type of motor starting is rendered more difficult than in the former, but the speed remains constant although the load varies. This motor is used for purposes where regularity in speed is essential, such as machine tools.

3. *Compound-wound Motors.*—These motors possess both a series and a shunt winding, and thereby have the combined characteristics of the former mentioned motors. The chief point in favour of these machines is that the speed is more constant for varying loads than that obtained by the use of the shunt-wound motor. It may be stated here that a compound-wound dynamo may be run as a motor. The application of this motor is somewhat limited. Shunt-wound motors with compound winding for starting purposes are employed in coal-washing machines and crushing machinery. This compound winding is only switched in during starting, and is cut out when the motor is doing its work.

The Lundell Direct-current Motor.—This type of motor is simple and compact. One energising coil is used for the field magnet. This coil supplies the exciting power where it is most needed, *i.e.* as near the armature as possible. There is a decrease of armature reaction, and also in magnetic leakage. The armature is of the slotted drum type. The core is composed of thin soft iron laminations, the conductors being wound in grooves in the core surface, so that they are protected from mechanical injury by being positively driven and able to withstand great torque when overloading occurs. The brushes are in a fixed position, and are made of carbon. They are arranged radially round the commutator. The terminal box is fitted at the commutator end. Two holes are provided for receiving the cables. The bearings are self-aligning, and self-oiling lubrication is performed by rings resting on the shaft in slots in the brushes, and dipping into the oil, thereby feeding the shaft with fresh oil when it is revolving.

To reverse the direction of rotation of continuous current motors it is only necessary to reverse either the connections at the armature terminals or those at the field terminals, *but not both.* Reversing switches are generally employed to effect the above when it is necessary frequently to reverse the motor.

Alternating Current Electro-Motors

In the single-phase motor the construction is somewhat similar to the continuous current motor. In some respects it is superior to the three-phase motor, but it possesses the disadvantage of having a commutator at which sparking is frequent. The efficiency is also very low. Another disadvantage possessed by the single-phase motor is that it cannot be operated at high voltages, whereas there is practically no limit to the

pressure which can be adopted in a polyphase motor. It, however, has the advantage of a great starting torque. The three-phase motor is much more in use in colliery work. This motor is constructed in two separate parts, namely, the rotor (Fig. 21), which is the revolving part, and the stator (Fig. 22), which remains stationary. The rotor is equivalent to the armature in a continuous current motor, and the stator takes the place of the field magnets. In the stator the windings are arranged in three sections, each section of coils being connected to one of the three cables coming from the generator. The rotor may be of the "squirrel cage" or the "wound" type. In the "squirrel cage" type of rotor, single conductors are laid in ducts in an iron core. All the conductor ends are joined up to two copper rings which form the ends of the rotor, thus completing the circuit throughout. In the "wound" type the conductors are *wound* on the iron core, and they are all short-circuited to three slip rings fixed on the shaft, but

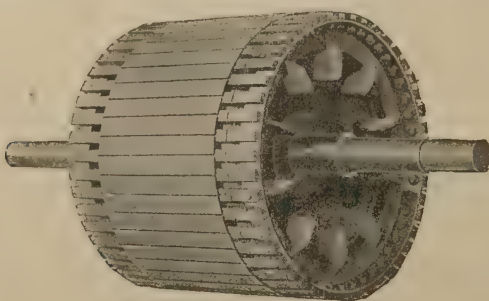


FIG. 21.—Rotor of polyphase motor.

insulated from it. The action of the motor is as follows:—When the current is switched on, the windings on the stator produce a revolving magnetic field in the interior of the motor. The lines of force in this revolving magnetic field cutting the conductors or wires on the circumference of the rotor causes an induced electromotive force to be set up, which in turn attempts to follow up the magnetic field, and so the rotor revolves. On the application of a load the action of cutting the lines of force will be increased, while the speed will be decreased slightly. The electromotive force induced in the rotor is increased, so that more current is taken and a greater torque is exerted to deal with the increased load. It is necessary for the rotor to revolve at a slightly slower speed than that of the rotating magnetic field, in order that power may be taken from the stator to cope with the load. The difference in speeds is termed the "slip." These polyphase motors are automatic in action, and self-starting. They have the advantage of possessing no commutator, so that all possibility of sparking is obviated. The machine requires little attention beyond

lubrication, which is generally automatic in action, so that inspection once a week is all that is necessary. Where large powers are required, and consequently great starting torque, slip rings fixed to the shaft are connected to the coils of the rotor (see Fig. 23). A "wound" rotor is required for large powers, as a greater starting torque is obtained, and at the same time keeping down the heavy induced currents from the line circuit. This is obtained by inserting a resistance in series with the coils of the rotor, contact being effected by the slip rings mentioned previously. An outstanding advantage of this motor for colliery work is that the speed is practically constant. No wastage of

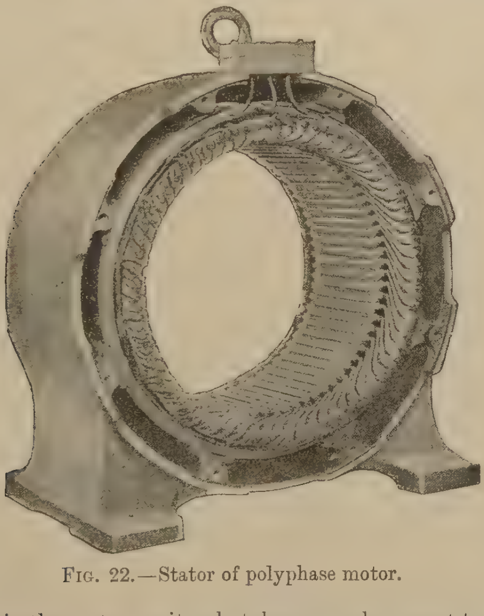


Fig. 22.—Stator of polyphase motor.

power occurs in the motor, as it only takes enough current to acquire the necessary torque. Fig. 23 shows a 120 horse-power three-phase motor.

To reverse the direction of rotation of a three-phase motor, reverse any two of the connections at the terminals of the motor. In a two-phase motor, reverse one of the phases only. A motor, of course, cannot be reversed *while running*. It must be first stopped, then reversed, and then started slowly in the usual way.

Motors for Coal-Cutting Machines

The continuous current type of electric motor is generally adopted for coal-cutting machines. In fiery mines and in dusty atmospheres

the motors of coal-cutters should always be enclosed, and gas-tight. For such work the polyphase motor is now coming greatly into favour, principally owing to the fact that alternating current may be used at high tension for transmission into the mines, where it may be transformed to a suitable voltage for use in the coal-cutting machines, and having no commutator or brushes is less liable to sparking.

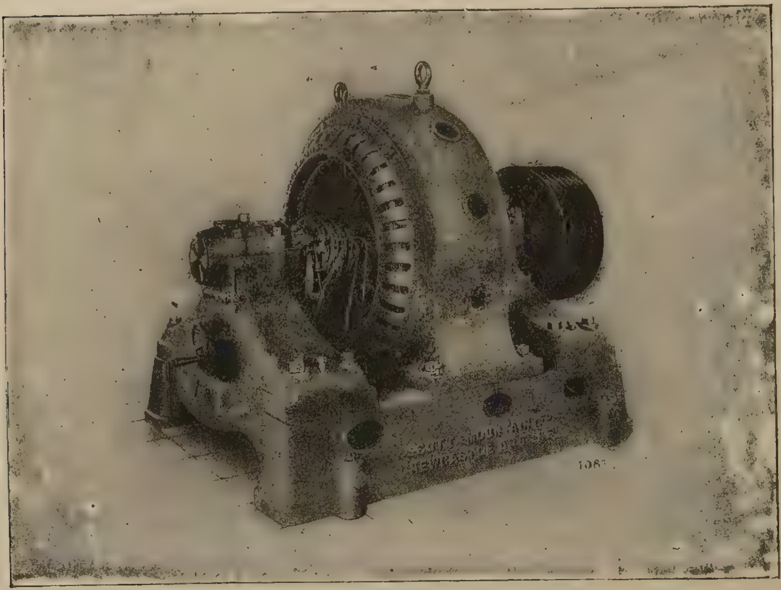


FIG. 23.—120 H.P. three-phase motor.

MOTORS FOR HAULAGE AND PUMPING

For endless rope haulage the shunt-wound C.C. motor is probably the most suitable, as it gives practically constant speed for all loads. One disadvantage it possesses is that it does not start well against a heavy load, necessitating the insertion of starting resistance in the motor circuit. Compound and series-wound motors are suitable for main and tail haulages, and also in traction work. The first named is frequently adopted for operating pumping gear and also coal-cutters.

Fig. 24 shows an enclosed type of electro-motor suitable for use in fiery mines. Fig. 25 shows a semi-enclosed type of electro-motor suitable for colliery work.

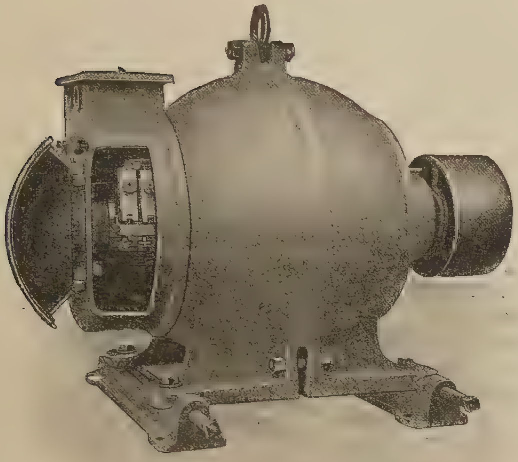


FIG. 24.—An enclosed type of electric motor, with inspection cover thrown open.

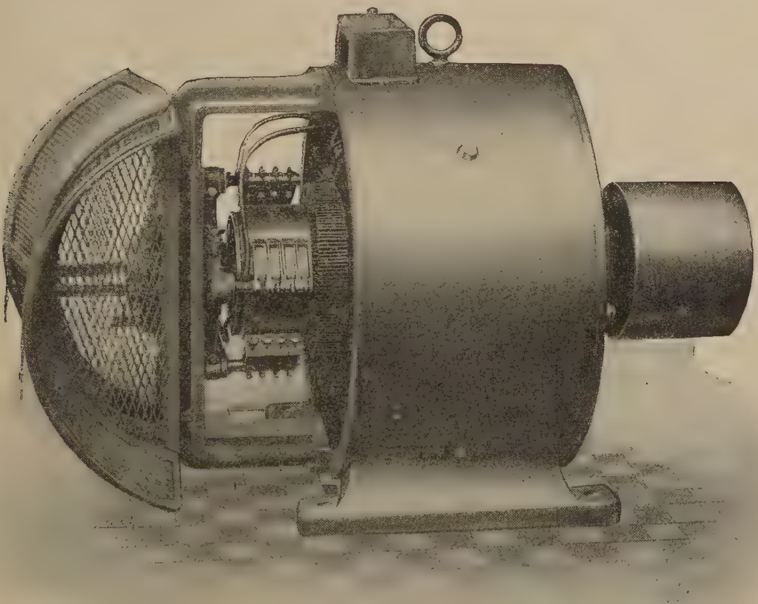


FIG. 25.—A semi-enclosed type of D.C. electro-motor, with protecting covers for commutator and brush gear.

Motor-Generator

As the name suggests, we have two machines coupled together. The one, with current supplied to it, drives the other, which in turn delivers current. The applications of the motor-generator, or "booster," as it is often called, are (1) transforming a high to a low voltage with an increase in current, (2) for raising the voltage at the end of a long feeder main, thereby making up for loss of pressure in the feeder main, and (3) for converting alternating current to continuous, the motor in this case taking alternating current, while the generator gives out continuous current. In practice the usual form has two fields and two armatures mounted on one spindle, connection being made by means of a shaft coupling between the two machines. These machines are self-regulating, as the main current flows through the field and armature of the generator in series with the line. When the load on the outside circuit is increased the field strength is increased in the booster, and the additional pressure is thus supplied to the booster circuit. For long distance transmission the mains or conducting copper cables must be necessarily thin owing to the heavy price of copper. As high-pressure current may be along mains of small sectional area, it is possible to utilise the booster to transform down this high pressure to a pressure suitable for the work to be done. Fig. 26 shows a modern type of motor-generator.

Static Transformers

As it rarely happens that high-pressure current, say at 3000 volts, can be used directly, some means must be found to reduce it, just as we would reduce a high to a low speed by reduction gearing. The apparatus most generally used to perform this function is the static transformer. In this form of transformer there is no revolving part whatever. It possesses two circuits, the "primary" and the "secondary." Suppose a soft iron ring to have two windings, one of thick, the other of thin wire, placed diametrically opposite on its circumference. The alternating current from the generator flows round the primary coil on the one side, and causes fluctuations to be set up which penetrate the other coil on the other side, which is called the secondary, thus causing an E.M.F. in this coil.

$$\frac{\text{The E.M.F. in secondary}}{\text{The E.M.F. in primary}} = \frac{\text{number of turns in secondary}}{\text{number of turns in primary}}.$$

Transformers may be used (1) in which alternating current is generated at low pressure and transformed up to a high pressure, (2) in which alternating current is transformed down from a small current with a high voltage to a large current with a low voltage. These transformers are called "step up" and "step down" respectively.

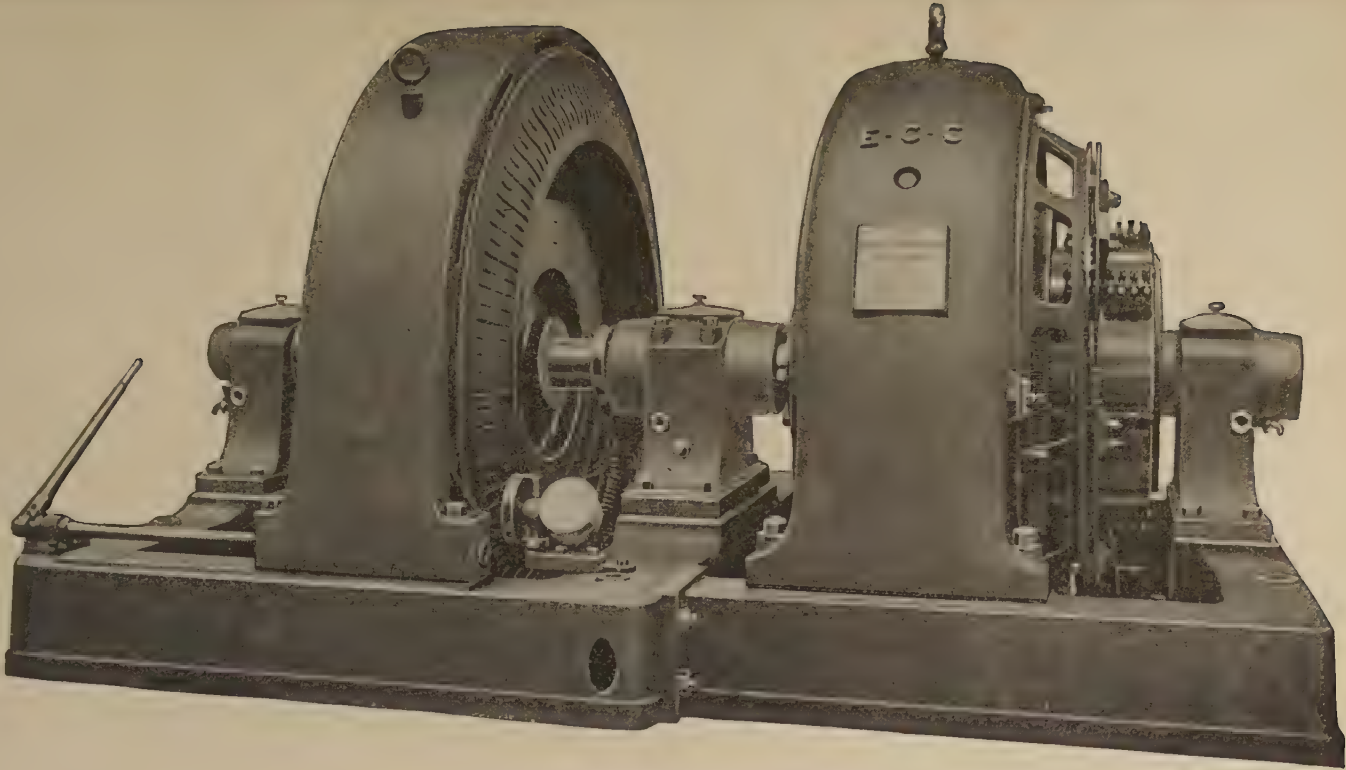


FIG. 26.—A modern type of motor-generator.

In the "step up" transformer the primary coil consists of few

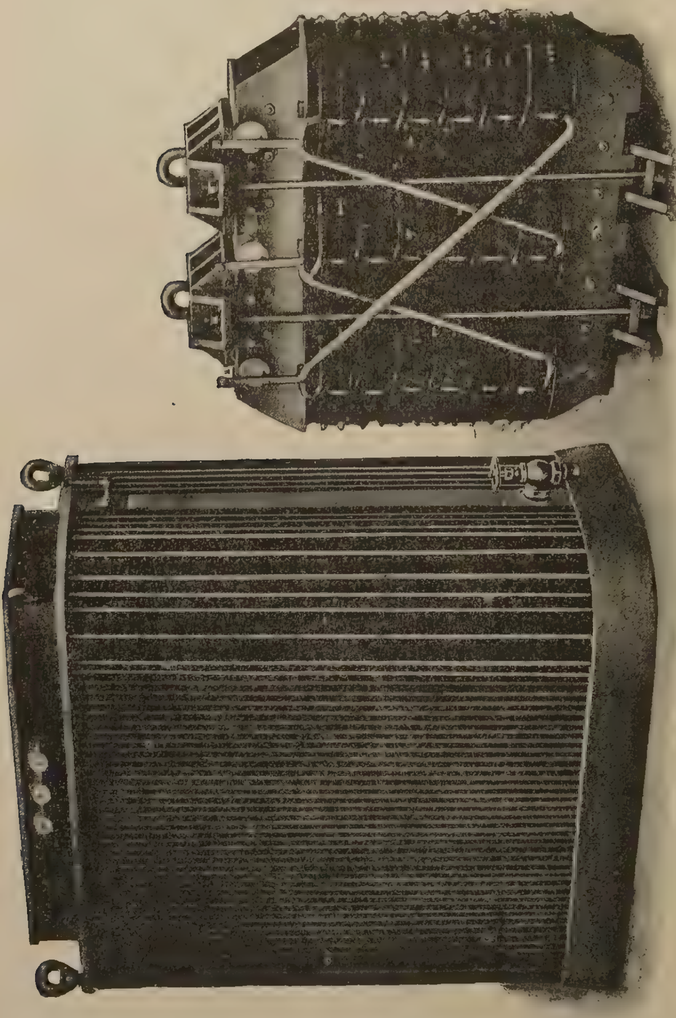


FIG. 27.—Westinghouse transformer removed from case.

turns of thick wire, and the secondary has many turns of thin wire. In the "step down" transformer the reverse is the case.

The main loss in transformers is due to hysteresis in the iron core, so that good material and careful design are very essential. There are also losses due to magnetic leakage and eddy currents. The General Electric Company make oil-cooled and air-cooled transformers, but recommend the air-cooled transformer for large sizes. Fig. 27 shows a modern transformer.

Transformers are made for two-phase and three-phase alternating current. Two transformers may be used in connection with a two-phase generator for transforming to a high pressure for a three-phase circuit.

Rotary Converters, or *Double Current Generators*, as they are sometimes called, are machines resembling an ordinary dynamo, with slip rings at one end of the armature, and a commutator at the other. A rotary converter, if supplied with continuous current, will give alternating current, and *vice versâ*; if supplied with continuous current, it will run as a motor; if with alternating current, it will run as a synchronous motor. If driven by mechanical means, it will deliver continuous or alternating current.

Care of Electrical Plant

So great advances have been made in the manufacture of electrical machines, that they should with ordinary care last for many years without giving trouble.

Miners and others who have charge of dynamos and motors should remember that cleanliness is the leading factor in the maintenance and efficient running of same. The majority of faults in electrical machines may be attributed to ignorance, neglect, or abuse. Overloading is a frequent fault, which if persisted in will assuredly cause permanent damage sooner or later.

In starting up a new generator, great care should be exercised. Run the machine at a slow speed with the magnetic field slightly excited, to an external circuit, say, the driving of a motor and lighting of lamps. This will cause the armature to become dry. Armatures usually absorb moisture when new, or when left idle for long periods. A sheet of sand-paper should be wound round the commutator and the brushes put on top of this. On revolving the armature, the carbon brushes take the correct shape of the commutator. Loose wires and nut keys should not be allowed to remain in proximity to the machines. All bolts and nuts should receive periodic attention, being tightened when required from time to time. Keep the parts of the machine free from dust and oil, see that no dirt accumulates about the brushholders. The carbon dust falling from the brushes should be frequently wiped up. The carbon brushes are copper plated, so that good contact between the brushholder and brush is ensured. Copper gauze brushes are still used on some machines, but

the carbon brush finds more favour. If the commutator brushes and rocker gear are well designed there should arise little or no trouble at that part of the machine. There is a certain position of the brushes on the commutator where no sparking takes place. This position can be found by experiment, *i.e.* by moving the rocker gear one way or the other. It is important to see that the right tension is given to the springs which press the brushes on the surface of the commutator. If the brushes are too slack, sparking occurs, and often they jump over the commutator surface; while, on the other hand, if the brushes are too tight, ruts and hollow places appear on the commutator surface. Commutator greases and oils should be studiously avoided. The surface should be cleaned with a linen rag, and the least possible quantity of pure vaseline applied by means of a rag is all the lubrication that is required. When cleaning the commutator while the machine is in motion, never remove the brushes when the load is on. Waste should on no account be used, as it is apt to catch on the brushes and cause sparking. Slight inequalities and "flats" may be removed from the surface of the commutator by the use of fine sand-paper while the machine is in motion. If the commutator becomes rutty and grooved it should be taken out and turned to a true surface in a lathe. Should a motor revolve in the wrong direction it will be found that the connections have been reversed. Failure to start in a motor may be due to bad contact or short circuit, want of magnetism or overload. Care should be exercised in operating the starting resistance or controller of a motor. It should be worked slowly from stud to stud. Inattention to this has often caused failure in armatures. Electrical machines at pit-head of collieries and mines should be installed in buildings specially designed for the purpose, while motors working underground should be semi-enclosed or totally enclosed, depending upon the surroundings. In the case of electrically driven pumping installations underground, motor and pumps should be contained in a small room or shed.

Earthing of Dynamos and Motors

The Electric Rules require that all generators, motors, transformers, etc., using current above the limits of low pressure, be efficiently earthed.

The object of earthing is to reduce the risk of shock to a minimum. The main point to watch in efficiently earthing the apparatus is that a good earth, that is, a good connection to earth, is obtained. The best plan is to procure a copper plate, about 2 feet square, solder to it a copper connection, and sink the plate in the ground, near the generating station. The cable armouring is then earthed at this point, through the copper connection. Subsequently the generator, all transformers and motors, switch-gear cases, should be definitely earthed through the cable armouring.

A good earth may sometimes be obtained through a pump main, but care must be taken that the pipes make a good earth contact, otherwise the whole of the pump fittings will become alive should a discharge to earth occur.

Coupling Dynamos Together

It sometimes happens, in order to obtain additional power, that dynamos are made to run together and deliver current to the same supply mains. For this purpose, continuous current dynamos may be coupled in *series* or in *parallel*. If two dynamos are run in series the pressure will be approximately doubled, while the current will remain the same; if coupled up in parallel, the current may be doubled while the voltage remains constant. In running alternating current generators together an apparatus known as a synchroniser is employed in order to ascertain if the two machines are "in step," or, in other words, are reaching their maximum E.M.F. at the same moment. Once "in step," the machines are coupled together by means of a switch, the necessary connections having previously been made.

CHAPTER III

TRANSMISSION AND DISTRIBUTION OF POWER

The switchboard —Switches—Circuit-breakers —Time-lags—Fuses and cut-outs —Measuring instruments—Locating a fault —Testing insulation—Lightning conductors—Systems of distribution—Economy of high tension—Colliery electric cables—Tensile strength of conductors—Sizes of cables—British standard wire gauge—Current density in cables—Loss of pressure in cables —Details of copper-stranded conductors —Insulation of cables—Protecting the insulation—Types of cables used in collieries—Suspension of cables in shafts—Fixing of cables in shafts—Jointing of cables in shafts—Suspension of cables in roadways —Callender's cable clip or suspender—Joint-Boxes—Disconnecting boxes—Solid system or troughing—Howard's asphalt system —The Simplex system.

The Switchboard

All the necessary switches, ammeters, voltmeters, recorders, fuses, etc. are fixed on this board, and connection made from the generators to the circuit. The current for power and lighting is controlled from this point. The board is usually divided up into panels, each generator having a panel of its own, with the various switches, meters, cut-outs, and rheostats to control the magnetic fields of the generator. If a battery of accumulators is used to help the generating plant to supply the current over the "peak" of the load, a special panel is usually provided. Copper bars, rectangular in section, are used as a medium between the generator and circuit. These "bus-bars," as they are termed, are usually arranged in pairs, at the back of the switchboard. The best place for a switchboard in the dynamo or engine-room is determined by the space available and the emission of light. Care should be taken that no steam piping is placed near the board, as the heat has an injurious effect on the contacts. Slate and marble are used for switchboards. Care should also be taken to see that no metallic veins run through the material. Regarding main switchboards the Rules say :—

"The main switchboard shall be separated from the engine-room by a hard-wood rail not less than 3 feet from the front of the board. The space in front of the board shall be a platform raised not less than 6 inches above the floor level.

"If there are any connections at the back of the switchboard, there

shall be a clear space behind the boards of not less than 3 feet. If space is required for resistance frames or other electrical apparatus behind the boards, the passage way must be widened accordingly. No cable shall cross the passage way at the back of the board except below the floor or at a height of not less than 7 feet above the floor. The space at the back of the switchboards shall be accessible from each end, and, except in the case of low-pressure switchboards, must be kept locked up, but the lock must allow of the door being opened from the inside without the use of a key.

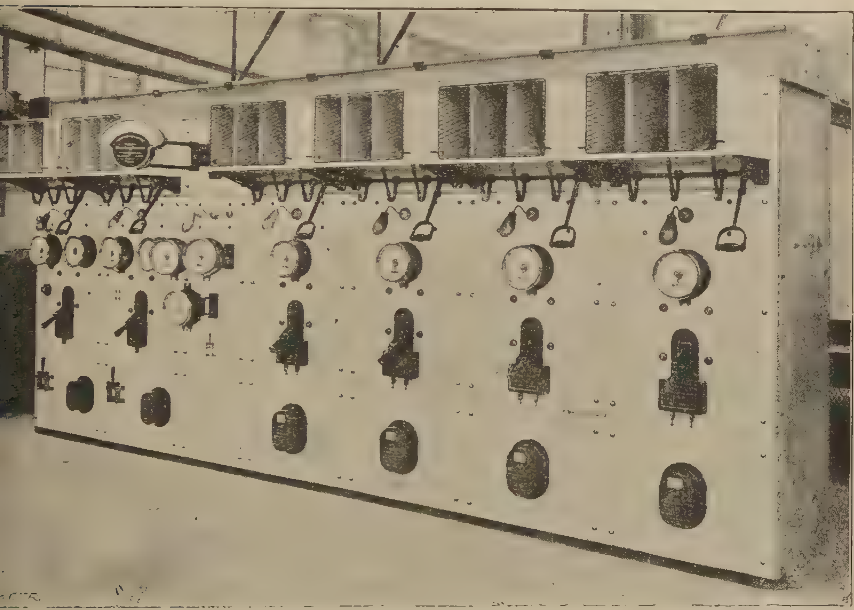


FIG. 28.—Main switchboard (front view).

"Where generators are paralleled, reverse current cut-outs shall also be provided.

"Where the supply is maintained continuously, the switchboard shall be arranged in sections so that all the pressure can be cut off from any section for the purpose of cleaning or repairing it. If the transmission lines from the generating station to the pit are overhead, there shall be lightning arresters in connection with the feeder circuits."

A good example of a modern colliery switchboard is shown in Figs. 28 and 29. It is situated in the power station of the Powell

Duffryn Steam Coal Co., South Wales. The two generator panels are seen in the left of the figure. The generators are three-phase 3000 volt 1000 K.V.A. Four large feeding cables take the current to the various points in the pit. The third panel from the left

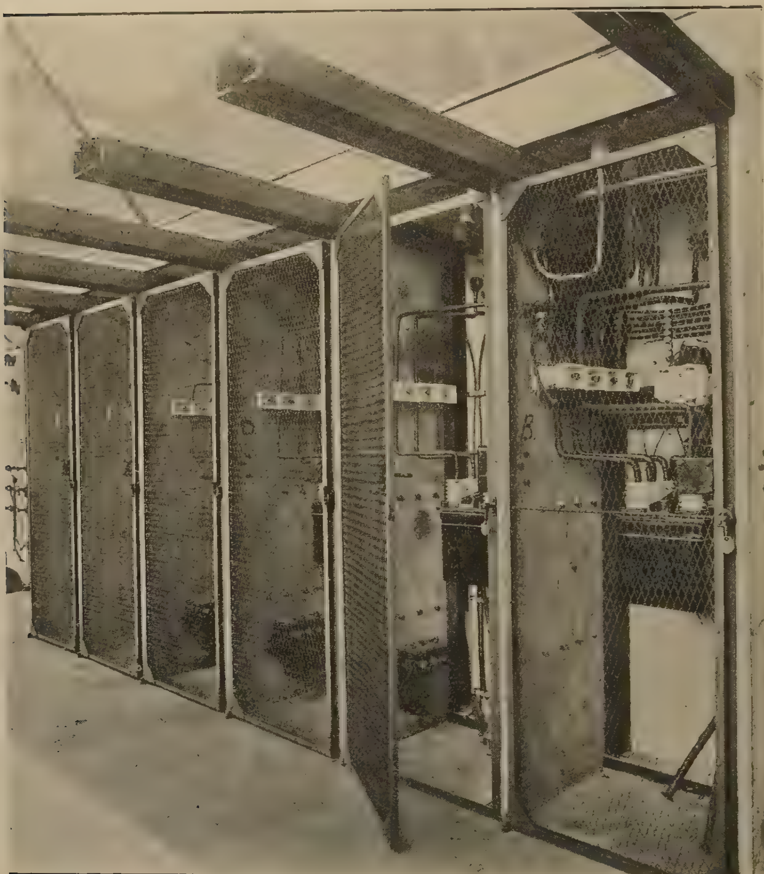


FIG. 29.—Main switchboard (back view).

contains the measuring instruments, while the remaining sections are auxiliary feeder panels. A three-pole air-break insulating switch is fixed at the top of each panel, and enclosed in an insulating division box with protecting screen. The back of the switchboard

is sectioned off so that separate cubicles or lockers are formed for

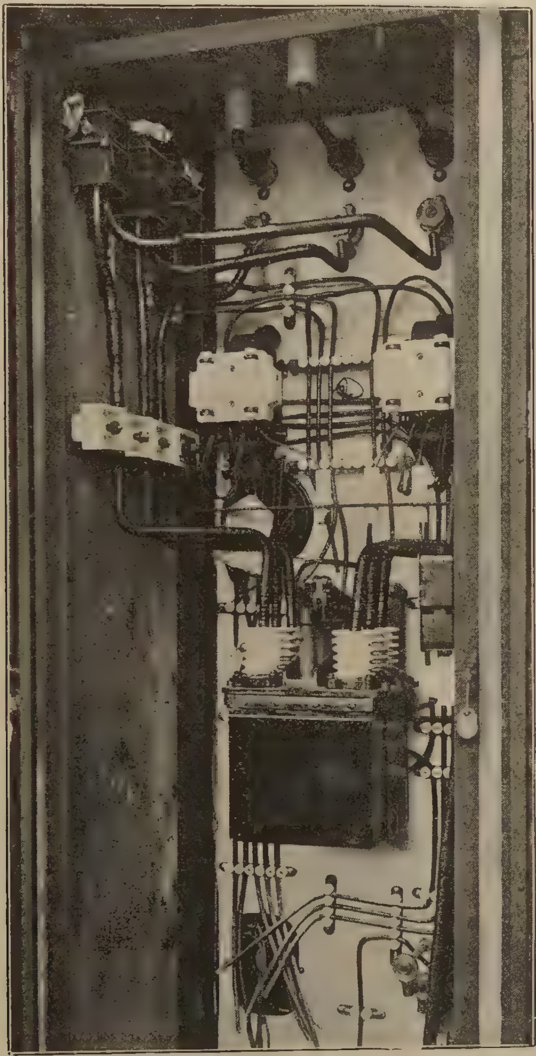


FIG. 30.—Panel connections.

the panels. Doors made from expanded metal are fitted to each cubicle, and will not open unless the insulating switch for that panel

is off. Therefore, when the cubicle is open, no current exists in the mechanism, and repair or adjustments may be safely carried on. An automatic air-break switch is put in series with the insulating switch. The feeders carrying the high-tension current are conducted overhead, thereby necessitating the use of lightning arresters to prevent damage to the generating plant during electro-static disturbance.

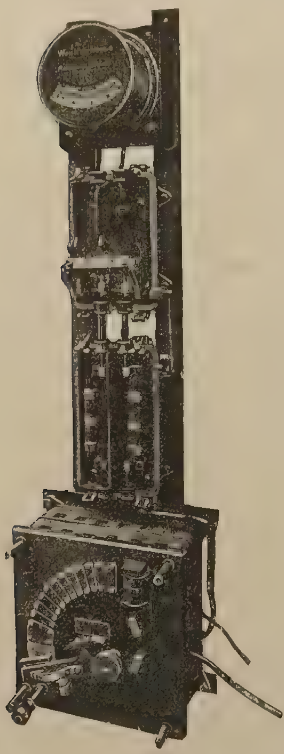


Fig. 31.—Underground switchboard (covers removed).

Fig. 30 shows the connections in one of the panels. Switchboards underground are constructed on the same principle as those on the surface if the mine is a non-fiery one, but if fire-damp is present switchboards of special construction are required.

A type of underground switchboard made by the British Westinghouse Company is illustrated in Fig. 31. This switchboard is for controlling direct current motors working at a pressure of 600 volts or under.

It consists of a line of unit switch and fuse boxes, ammeter frames, motor-starters, and bus-bar chambers.

Knife switches and enclosed fuses are employed, and all live parts are enclosed in cast-iron boxes.

The apparatus illustrated is capable of dealing with a motor of 33 H.P. at 500 volts.

Fig. 32 shows diagrammatically the apparatus and connections for a three-phase underground motor-control box for circuits up to 600 volts.

Switches

On the surface and in mines free from fire-damp the ordinary type of knife switches is generally used.

Fig. 33 shows one of these switches in the "on" position. The contact blades are of copper, and an insulating handle is provided for the safe working of the switch.

In mines where General Rule No. 8 of the Coal Mines Regulation Act applies a special class of switch has to be adopted. An

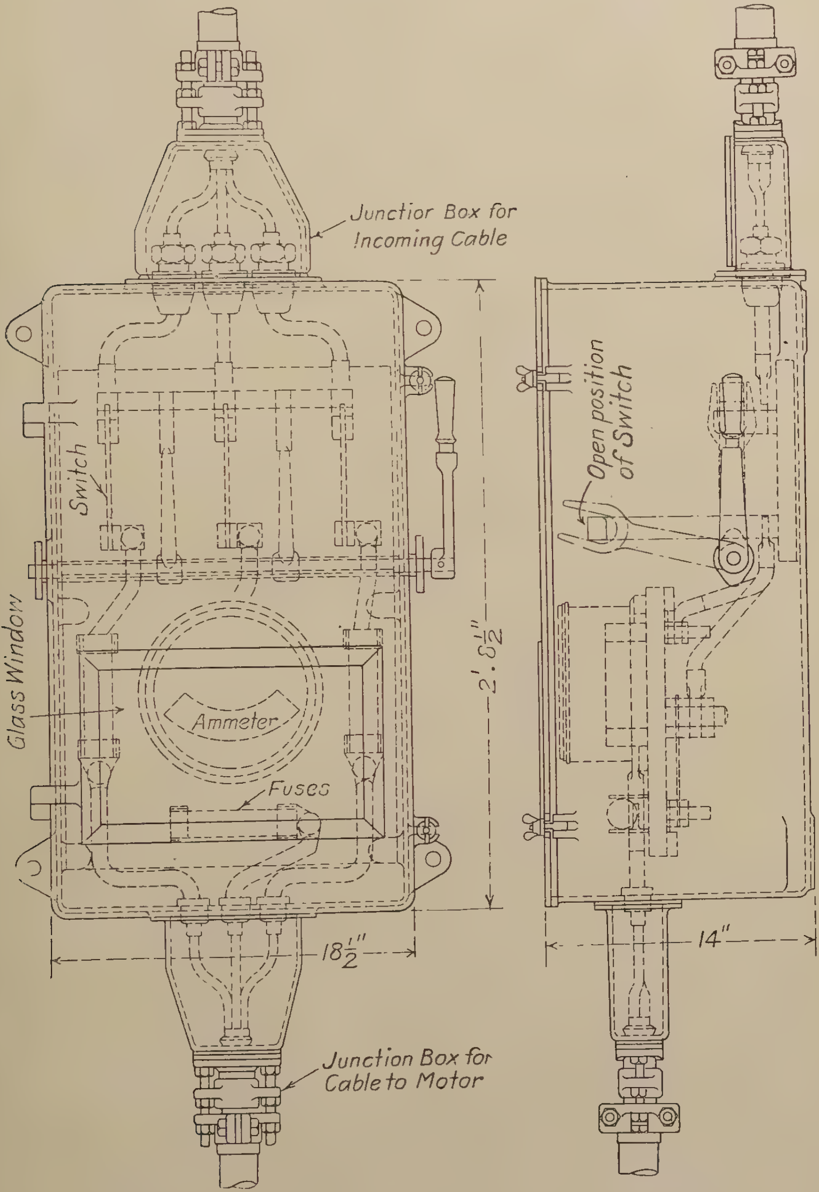


FIG. 32.—Connections for underground switchboard (three-phase).

Fig. 33.—Double-pole main switch.

enclosed type of switch for use in fiery mines is shown in Fig. 34.

The switch is suitable for circuits up to 600 volts. It is enclosed in a case of cast-iron lined with asbestos, and is provided with outside handle. The spindle passes through a gas- and watertight gland into the case, and the handle is made of highly insulating material. The hinged lid is provided with a rubber ring, so that when closed a perfect joint is made between the lid and the box. The above types of switches are designed by Johnson & Phillips of Charlton.

Switches which break under oil are also used in fiery mines. Fig. 35 shows an oil switch made by the Switchgear Company for potentials up to but not exceeding 3300 volts.

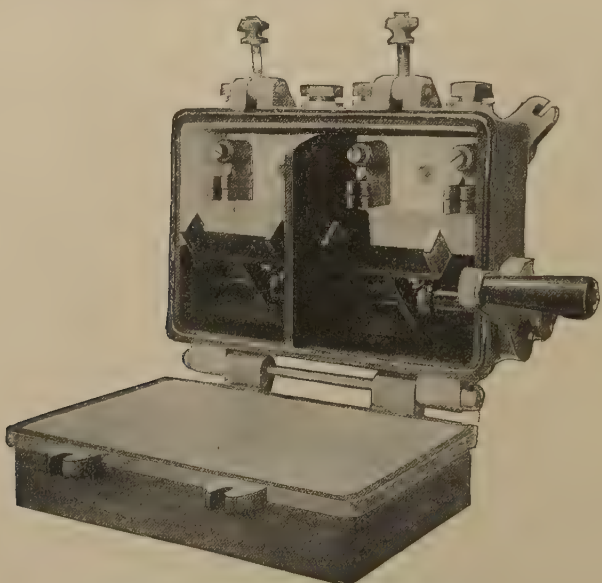


Fig. 34.—Enclosed switch for fiery mines.

The switch is provided with double-break knife contacts immersed in a single oil tank, and has barriers of treated wood placed between the poles to prevent the arcs from communicating. All live parts are effectually covered when the tank is in the working position.

Fig. 36 shows an oil switch by the same firm, designed for potentials above 3300 volts. The illustration shows the switch with the oil tank removed.

FIG. 35.—Oil switch (for potentials under 3300 volts).

The oil in the tanks of oil switches should be occasionally renewed, as the constant arcing in time tends to affect the insulating properties of the oil through the formation of a carbon deposit. Figs. 37 and 38 show two views of a tumbler switch for lighting circuits in the "on" and "off" positions.

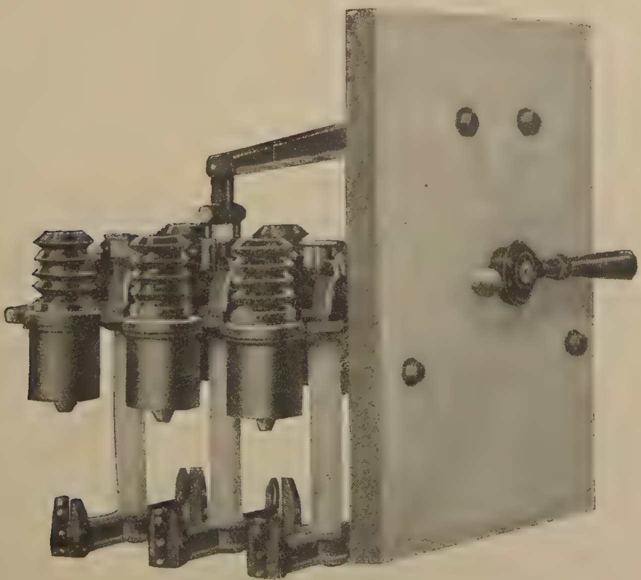


FIG. 36.—Oil switch with tank removed (for potentials above 3300 volts).

Water Switches are also recommended for use in situations where there is the risk of fire-damp accumulations. They consist of a tank or trough filled to a certain level with a solution of salt and water. Fixed to the bottom of this vessel is a cone-shaped metal terminal to which is clamped one of the mains.

Above the trough, pivoted on a horizontal spindle, is a single or double-bladed knife switch. The blades are usually shaped like the sector of a circle, and on the operating handle being raised the sector is lowered into the liquid, when of course the circuit is completed, the blades and the contact piece at the bottom of the trough being both in the water.

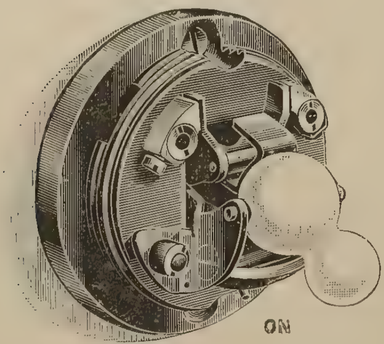


FIG. 37.—Tumbler switch ("on" position).

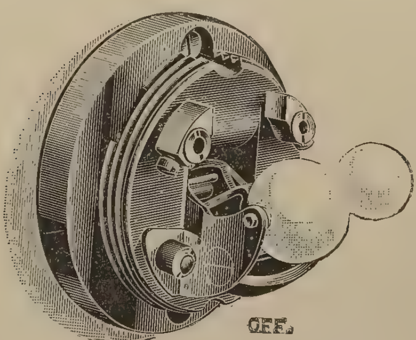


FIG. 38.—Tumbler switch ("off" position).

The liquid switch is frequently used for a starting switch, because the water, being of high resistance, chokes back the current at the first completion of the circuit. As the blades are gradually lowered this resistance is slowly cut out, because the distance between the fixed and movable contacts is being reduced. In this way the motor is enabled to start slowly and to gradually accelerate in speed.

Fig. 39 shows a form of liquid switch made by Scott & Mountain of Newcastle-on-Tyne. In this form a hand wheel is provided by means of which the central contact piece is raised or lowered. This movable contact works between insulating guides, and so cannot touch the outer case.

Starting Switches.—The ordinary type of starting switch or rheostat consists of a number of coils of iron wire which are connected up to a corresponding number of contact studs or buttons in such a manner that if a contact switch is passed from one stud to another a coil of the iron wire resistance is cut out of the circuit as each additional stud is passed.

A reference to Fig. 41 will serve to show the action of the starting switch. It will be noticed that there are a series of contact studs over which the switch has to pass in running the motor up to full speed. Now, if the starting switch is rested on the first stud, the motor will start, but as the whole of the iron wire resistance is still in circuit, the pressure is choked back, and the motor is allowed to start slowly. After the armature is in motion for a short period the starting switch is moved to the second stud. In doing this the coil or coils of resistance connected up to the first stud are cut out of circuit, and part of the resistance being thus removed the motor is enabled to gain in speed. In the same way, as the switch is passed from stud to stud additional coils of resistance are cut out, until, when the switch rests on the last stud of all, the whole of the resistance is out of circuit, and the motor is running at its maximum speed. The resistance is generally kept in an iron box or case fixed on the switchboard. In most modern starting switches a small electro-magnet, which is excited by the current, holds the switch lever on the last contact. If for any reason this magnet fails to become electrified, the switch is automatically released, and is pulled back by a spring which is attached to it, and against which it has to be pushed when the motor is being started, thereby preventing any possibility of starting with full current. The starting switch of a three-phase motor has three separate sets of resistance coils, and a three-armed switch is used. On starting the motor, each arm of the switch rests on the first contact stud of one of the sets of resistance coils. As the switch moves from stud to stud the resistance in each of the sets is gradually cut out.

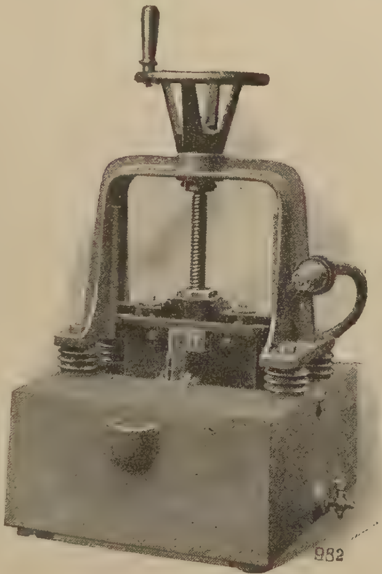


Fig. 39.—Liquid switch.

Circuit-Breakers

These are for the automatic breaking of the circuit when an excessive overload or short circuit occurs. Fig. 40 shows Statter &

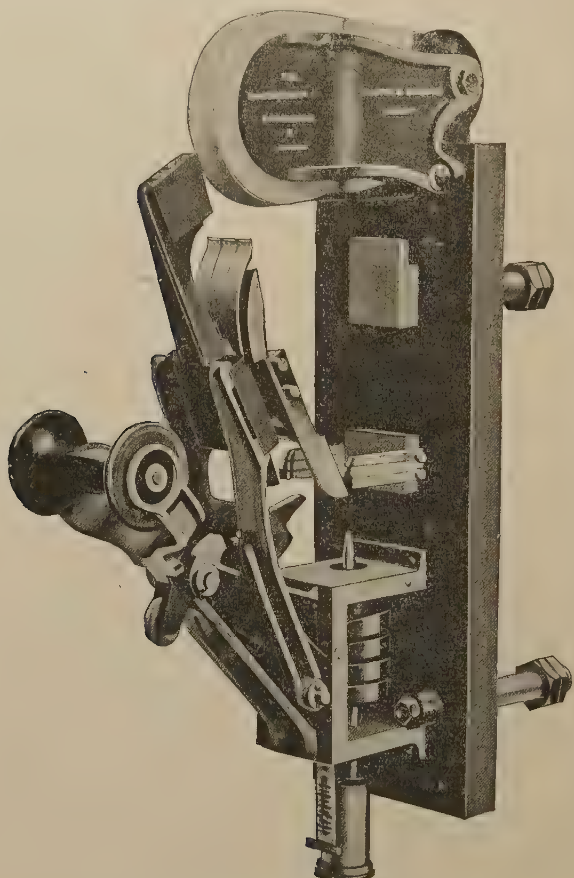


Fig. 40.—Circuit-breaker, with automatic release.

Simeon's patent circuit-breaker, designed for direct-current circuits at any pressure up to 1000 volts.

When being thrown into circuit, the circuit-breaker has to act against a spring, and when in the "on" position the breaker is held by a trigger catch. An electro-magnet having a movable core or

armature is fixed just below the trigger catch. When an overload or short circuit occurs, the movable core of the magnet is pulled sharply up, knocking off the catch and releasing the breaker, which is drawn quickly back by the spring.

A Magnetic Blow-out is also sometimes provided for use with a circuit-breaker for the prevention of arcing on the main contacts.

Time-Lags

These are apparatus for use in combination with circuit-breakers and motor-starters, whose function it is to regulate and control the action of the automatic releasing arrangement.

The employment of a time-lag is calculated to ensure safety to

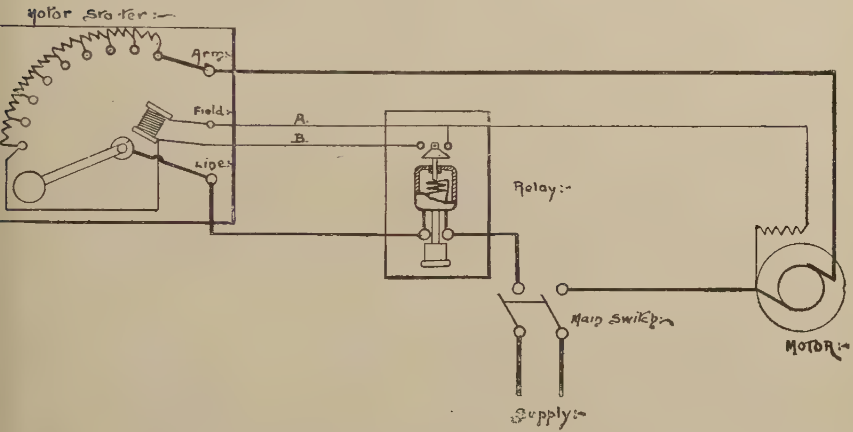


Fig. 41.—Method of wiring for no-voltage release starter, with time-lag relay.

the motor, reliable and definite action of the circuit-breaker, and general efficiency. The time-lag prevents the breaker from being opened by a sudden transitory overload, and will retard its action for a definite and adjustable period according to the amount of overload.

Should the overload be serious, as in the case of a short circuit, the action is absolutely instantaneous, while if the overload passes off before the circuit-breaker has opened the time-lag automatically resets itself.

It should be used on all important electric circuits.

Fig. 41 shows the method of wiring up to an ordinary no-voltage release starter, with a time-lag relay.

Statter's patent time-lag, made by the Switchgear Company, is one of the best of these instruments.

Fuses and Cut-outs

Fuses are used for protecting an electric circuit. Being the weakest part in the circuit, the fuse is burnt out when an excess of current passes, thus breaking the circuit and leaving it undamaged.

Fuses should be used on every independent motor or lighting circuit. They are generally mounted on the switchboard, and are enclosed in gas-tight boxes where there is a danger of fire-damp accumulations.

Fig. 42 shows a common type of fuse with raised terminals enclosed in insulating porcelain washers.

The accompanying table gives the approximate fusing currents of different kinds and sizes of wires used for fuses.

Approximate Fusing Currents (Sir W. H. Preece).

Current in Amperes.	Tin Wire.		Lead Wire.		Copper Wire.		Iron Wire.	
	Diameter inches.	Approx. S. W. G.	Diameter inches.	Approx. S. W. G.	Diameter inches.	Approx. S. W. G.	Diameter inches.	Approx. S. W. G.
1	0·0072	36	0·0081	35	0·0021	47	0·0047	40
2	0·0113	31	0·0128	30	0·0034	43	0·0074	36
3	0·0149	28	0·0168	27	0·0044	41	0·0097	33
4	0·0181	26	0·0203	25	0·0053	39	0·0117	31
5	0·0210	25	0·0236	23	0·0062	38	0·0136	29
10	0·0334	21	0·0375	20	0·0098	33	0·0216	24
15	0·0437	19	0·0491	18	0·0129	30	0·0283	22
20	0·0529	17	0·0595	17	0·0156	28	0·0343	20·5
25	0·0614	16	0·0690	15	0·0181	26	0·0398	19
30	0·0694	15	0·0779	14	0·0205	25	0·0450	18·5
40	0·0840	13·5	0·0944	13	0·0248	23	0·0545	17
50	0·0975	12·5	0·1095	11·5	0·0288	22	0·0632	16
60	0·1101	11	0·1237	10	0·0325	21	0·0714	15
80	0·1334	9·5	0·1499	8·5	0·0394	19	0·0864	13·5
100	0·1548	8·5	0·1739	7	0·0457	18	0·1003	12
120	0·1748	7	0·1964	6	0·0516	17·5	0·1133	11
140	0·1937	6	0·2176	5	0·0572	17	0·1255	10
160	0·2118	5	0·2379	4	0·0625	16	0·1372	9·5
180	0·2291	4	0·2573	3	0·0676	16	0·1484	9
200	0·2457	3·5	0·2760	2	0·0725	15	0·1592	8
250	0·2851	1·5	0·3203	0	0·0841	13·5	0·1848	6·5

Automatic cut-outs are also frequently employed for the better protection of electric circuits.

There are three different types of these in general use.

1. *Excess Current Cut-outs.*—These act the part of fuses, and break the circuit when an overload occurs.

2. *Minimum Current Cut-outs.*—These act when the current falls to a certain percentage below the maximum, usually about 15 per cent.

3. *Excess Non-return Current Cut-outs.*—These act as fuses, but break the circuit only with a return current. They are required in colliery installations when dynamos are run in parallel.

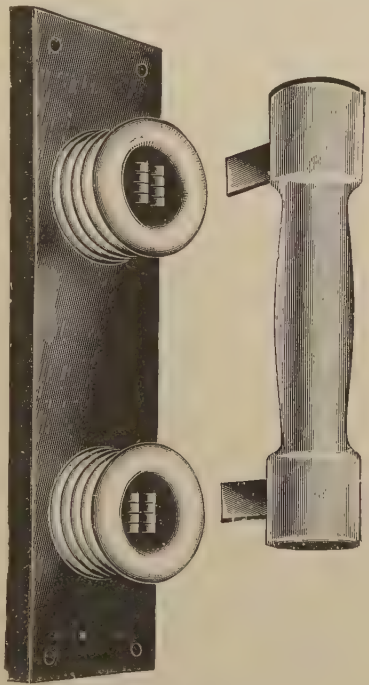


FIG. 42.—Safety fuse.

Measuring Instruments

Various instruments are used for the purpose of electrical measurement. These are usually situated on the switchboard, this being the most convenient position, as the current is controlled and distributed from this point.

The Voltmeter, as its name implies, is an instrument for measuring the potential difference between two points at any particular time, the measurement being in volts. The principles upon which their action depend are, *firstly*, the effect of heating in a wire due to the current. Such instruments are known as *hot-wire voltmeters.* By means of suitable mechanism the expansion of the platinum wire causes the pointer to move across a graduated scale, the deflection denoting a certain number of volts. The advantages of this hot-wire instrument are—(1) they may be used on continuous and alternating current circuits; (2) the errors due to self-induction are done away with by having no iron parts or solenoids; (3) since the heating effect is utilised as the principle of this instrument, then the errors which occur in other types of voltmeters due to heating are, in this case, eliminated. The disadvantages are—(1) the zero point is apt to change, and the deflection lags a little,

due to the wire taking some time to reach its final temperature; (2) should a current slightly over the maximum pass through the instrument, the thin wire, due to the great temperature, fuses; (3) the electrical energy wasted in some instruments of this type is excessive. *Secondly*, instruments in which the *magnetic effect* of the current on a magnet takes place, or these conditions reversed. The Weston Moving Coil instrument is a good example. Between two permanent steel magnets a soft iron cylinder is fixed. A moving coil of copper wire embraces this soft iron cylinder, and is free to move in the intense magnetic field thus produced. A hair spring is fixed to one end of the coil, the other end of the spring is anchored to the instrument. At the other end of the coil a spring exactly similar to the one mentioned above is also in use. As these springs are made from a non-magnetic metal, and their spirals are coiled in opposite directions, the temperature effects are neutralised. The current passing to and from the coil is carried by these springs. Fixed to the coil is a pointer made of aluminium, one of the non-magnetic metals. A graduated scale is provided, over which the pointer travels. An iron casing protects the working parts from the disturbing influence of outside magnetic fields. When a current passes through the coil of the instrument it tends to take up a position at right angles to the magnetic field, so that the lines of force caused by the current coincide with the lines of force due to the magnet. This instrument is "dead beat," because the eddy currents induced in the framework of the coil retard the motion. The reading on the instrument depends upon the magnetic field and the pressure of the current. Some of the advantages claimed for this instrument are—(1) they are "dead beat"; (2) no errors from the effects of hysteresis, as in other instruments; (3) working parts are of light construction and highly sensitive, and the power absorbed is small. A few of the disadvantages are—(1) the spring and magnets weaken after some considerable time; (2) a reversal of the current causes the pointer to swing in the wrong direction most violently against the sides of the instrument, thus causing it to bend.

The "Moving-iron" Voltmeter may be mentioned here, as its principle is somewhat similar to the foregoing instrument, the conditions, however, being reversed. A specially constructed solenoid with a strong and uniform magnetic field is situated at the centre. At the ends of the solenoid the magnetic field is strong owing to the lines of force leaking at the sides or ends. Two pieces of soft iron are suspended in the core of the solenoid. One piece, short in length, tends to move towards the centre. The other piece, which is long, tends to move towards the wires at the sides or ends. The strength of the magnetic field and the current determine the motion of the pointer over the scale. Fig. 43 shows the external appearance of a voltmeter.

The Ammeter (Fig. 44) is an instrument for indicating the strength of the current in amperes flowing in any part of the circuit at a given time. The ammeter is practically similar in construction to the voltmeter, but has a much lower resistance than the latter. Ammeters are made on the hot-wire and moving coil and iron principles.

Ammeters are connected in series with the main circuit. Voltmeters are connected directly *across* the mains by means of a thin shunt wire.

A Wattmeter is an instrument which measures the watts expended

Fig. 43.—Voltmeter.

in a circuit at a given instant. A well-known make is that known as Siemens'. The principle may be stated as follows :—

A moving coil wound with thick wire of a low resistance is in communication with the main circuit. Two coils are necessary to measure the wattage, one for amperes and one for volts. The thick wire coil is known as the ammeter coil. Another coil of high resistance wire is connected as a shunt to the mains where the watts expended are to be measured. This stationary coil is known as the the voltmeter coil. At the normal position the coils lie at right angles and the fingers point to zero. When the current is switched on it

circulates round the moving coil, and a small percentage of it is shunted through the fixed coil. A turning movement is exerted, and it is proportional to the two currents multiplied, so that the reading in volts multiplied by the reading in amperes equals the watts expended. For use on alternating current circuits a special non-conducting case is employed to cover the working parts, and to prevent eddy currents influencing the coils.

Electricity Meters are used for measuring the quantity of electricity in a given time. There are different classes of meters. 1st.

Fig. 44.—Ammeter.

Clockwork Meters, containing two pendulums carrying coils of thin copper wire. Underneath, two solenoids are fixed, through which the main current passes. By using suitable connections, the direction of motion of one pendulum is retarded, while the other is accelerated. The difference between the two motions is registered on dials, and the reading denotes the energy or quantity of electricity supplied. These meters may be used on continuous and alternating current systems, and are self-winding. 2nd. Electrolytic Meters. There are many well-known makes, such as Wright's, Edison, Long-Schattner, and Bastian. A short description of the latter may suffice to show

the principle on which they depend for their action. A dilute solution of sulphuric acid is contained in a glass cylinder of about 2 inches diameter and 12 inches long. Evaporation of the liquid is eliminated by a top layer of paraffin oil. Two platinum electrodes are contained in a vulcanite holder at the extremity of the glass cylinder. The top of the cylinder is fitted with a porcelain cover tapped by two vulcanite tubes through which are threaded the lead wires carrying the current from the terminals of the meter to the electrodes in the vulcanite holder. A sheet iron case encloses the instrument, an inspection window being fitted in front. The electrolyte takes up a zero position, and when the current is switched on the electrolyte is decomposed into two gases, hydrogen and oxygen. By the law of Faraday, the amount electrolysed in a given period is proportional to the total quantity of electricity which has passed in that period, the level of the liquid being taken as a measure of the quantity of current in ampere-hours which causes the liquid to fall.

The Ohmmeter is also essential on electric circuits at collieries. One of the best types of ohmmeter is the N.C.S. Leakage Indicator. This instrument is of the centre-zero moving coil type, and is for use on direct-current two-wire circuits with both mains insulated. There are three terminals on the instrument, the two outside terminals being connected to the positive and negative mains respectively, while the centre terminal is connected to earth. A high resistance, 200,000 ohms, is connected across the mains, and the mid-point of this resistance is earthed through the moving coil. By this means a reading is obtained on the ohmmeter should there be any defect in the insulation of either of the two mains, a two-way switch being provided so that the instrument may be connected with either main and earth.

Another type of leakage indicator made by Nalder & Thompson is designed for use on alternating current circuits, whether single-, two-, or three-phase.

The principle made use of in these instruments is that of superimposing a small continuous current on the alternating current system.[1] This continuous current is measured by means of a permanent magnet moving-coil instrument, which is unaffected by alternating currents.

The source of direct current may be either a battery, small generator, or the exciter of the alternating current generator.

The moving-coil instrument is calibrated with the known voltage of the battery, small dynamo, or exciter, so as to give direct reading in ohms of the insulation resistance between the system and earth. In addition to the scale of ohms, the dial of the instrument has also a scale of amperes marked on it. The actual leakage current is never

[1] *Electrical Magazine*, March 1907.

greater than the number of amperes shown by the reading of the instrument, though under certain circumstances it may be less. If the insulation resistance of the system falls below the Home Office requirements, a fuse blows; the blowing of the fuse closes a local bell circuit which keeps the bell ringing until the insulation is repaired.

Fig. 45 shows the general arrangement for completely insulated circuits.

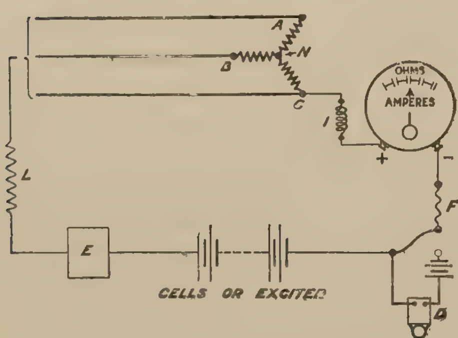


Fig. 45.

A, B, and C are the star windings of the generator. The leakage indicator is connected as shown between the point C and the large inductive resistance I, which is in series with the cells or exciter through the fuse F to E, the earth.

The object of the large inductive resistance is to prevent the flow of any appreciable alternating current to earth through the instrument.

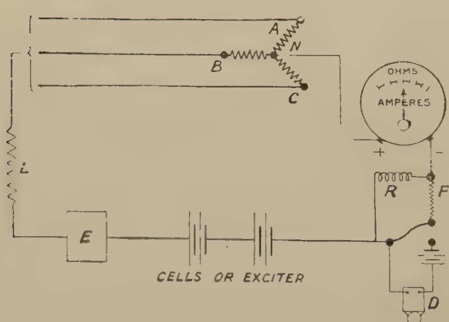


Fig. 46.

Fig. 46 shows the arrangement for circuits with earthed "neutrals." It will be noticed that the instrument is inserted between the neutral N and earth. The resistance of the instrument, fuse, and battery is only 5 ohms, or with an exciter only 1 ohm, consequently the earthing of the neutral is in no way impaired. To prevent the neutral wire being entirely disconnected from the earth when the fuse blows, a resistance R is connected in parallel with the fuse; this resistance is just large enough to prevent the current through the instrument, due to the leak, doing any damage. When the fuse F blows, the small spring switch to which it is attached on its lower side (see diagram) is allowed to fall, thus closing the bell circuit and ringing the bell D.

Locating a Fault

Once a fault in the insulation of a main circuit has been recorded by the warning bell of the leakage indicator, the next thing to be done is the localisation of the fault.

In direct current work an apparatus frequently used is Evershed's combined ammeter and voltmeter. The mode of procedure is shown diagrammatically in Fig. 47, and is as follows:—

Provide an adjusting tank, about 2 feet deep and 1 foot square,

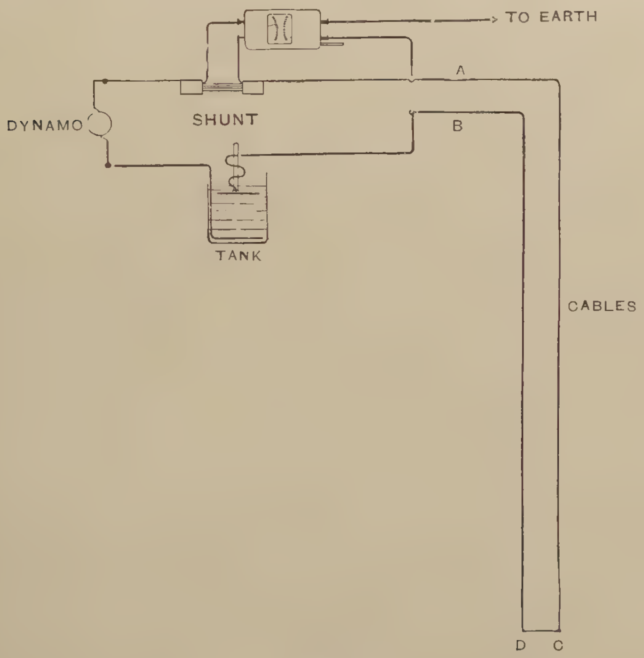


Fig. 47.

constructed of wood, and coated inside with pitch. On the bottom place a loose plate of iron, say 9 inches square, from which an insulated lead is brought out. A second plate is carried by a wood rod in such a manner that its height can be adjusted in the tank. The tank is then filled with a solution of soda, and forms a convenient means of adjusting the current by varying the height of the adjustable plate.

Now connect the two cables together at the bottom of the pit, as at D and C in the diagram.

Next connect, as shown in sketch, the dynamo to the cable circuit through an appropriate ammeter shunt and the adjusting tank (in which the plates should at first be as far apart as possible). Then run up the dynamo to a steady voltage, and increase the current by means of the adjusting tank until there is a good reading on the voltmeter indicating the drop of volts between point A and earth.

Then, with *the same current*, measure the volts between point B and earth. Then the ratio of the two volt readings gives the position of the fault. Call the volts between A and earth x, and those between B and earth y. Then—

$$\frac{x}{y} = \frac{\text{distance of fault from A,}}{\text{distance of fault from B,}}$$

which is equivalent to saying that the *distance of fault from A is*—

$$\frac{x}{x+y} \times \text{total length of the looped cables.}$$

The formula assumes that the resistance of the cable is uniform throughout its length.

Testing Insulation

For testing the insulation of generators, motors, and cables, the two instruments most usually employed at collieries are the "Ohmer" and the "Megger."

The "Ohmer."—This instrument may be used for 500-volt and 1000-volt circuits, and gives the following ranges of resistance: To 20, 50, or 100 megohms, at 500 volts, and up to 50 or 100 megohms at 1000 volts. It consists of a generator and ohmmeter of the electro-static type. The ohmmeter is independent of all external fields. It is also made dead-beat by magnetic damping. The working of the set is as follows (see Fig. 48): One of the generator terminals is connected to the quadrant A of the ohmmeter, and the same terminal is connected through a resistance R to the other quadrant B of the ohmmeter. The other terminal of the generator is connected to the vane V. A connection from quadrant B goes to the main or line to be tested, and the vane V is connected to earth. When the insulation resistance between the earth and main or line is infinite, then no current flows through the resistance R, and the vane V registers infinity as shown in the diagram. When current flows from E to L, there is a drop of potential due to the current flowing through R. The two quadrants A and B are then at different potentials, and the vane V registers a new position on the scale.

The "Megger."—This instrument also consists of an ohmmeter of the moving coil type, combined in one box with a hand generator or dynamo to provide current for the tests. When making a test with

the "megger" the hand dynamo has to be turned at a rapid rate—from 100 to 120 revolutions per minute (see Fig. 49).

In testing circuits of considerable electro-static capacity the full

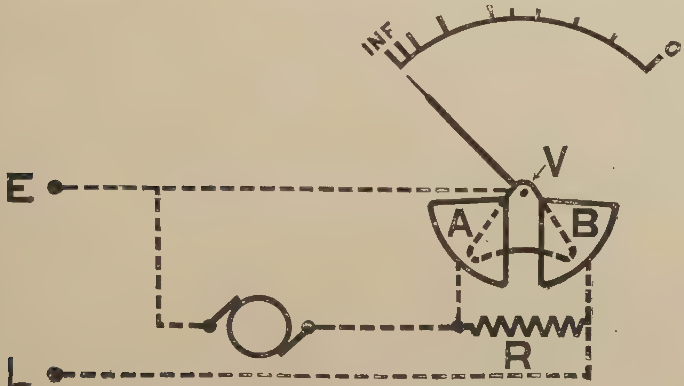


FIG. 48.—Diagram of "ohmer" connections.

speed of 120 revolutions per minute has to be maintained for at least a minute before taking a reading.

In testing insulation between a circuit and earth, the *line* terminal

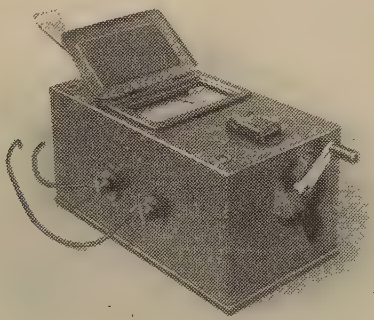


FIG. 49.—The "megger."

of the instrument is connected to the circuit, and the *earth* terminal to a good earth. For testing between two wires, connect one wire to each terminal.

Fig. 50 shows the method of connecting up the "megger" in testing the insulation of a cable.

Lightning Conductors

When thunder-clouds charged with electricity strike each other or some object on the earth, the air is ruptured and breaks down under the severe stress produced. The line of fracture or rupture shows up clearly by becoming electrically incandescent, and this phenomenon is known as lightning. It is a well-known fact that electricity takes the nearest and least resistive path to earth. Metals are good conductors of electricity, but building materials offer more resistance, so that chimney stalks, pinnacles, spires, etc.,

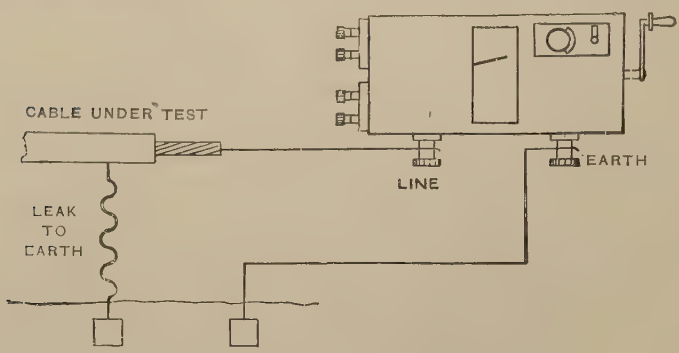


Fig. 50.—Connections for insulation test.

should be fitted with a lightning conductor to convey the electricity to earth without causing damage. Lightning conductors are generally made from copper tapes or ropes. Iron has been used for this purpose, but the sectional area required is so much greater, and deterioration by rust renders frequent renewals necessary. If the conductor is too small in sectional area it may be fused by a heavy charge, thus leaving the building or chimney stalk unprotected from further shocks. A suitable size of copper tape is $\frac{3}{4}$ of an inch broad by $\frac{1}{8}$ inch thick. When installed on a chimney stalk the conductor should be connected to a rod, the end of the rod branching into several points. As lightning discharges have extremely high pressures, sometimes amounting to millions of volts, it is very necessary that the conductor should have a low resistance. It is customary to bed a copper plate about 3 feet square in the earth, connection being made to the lower end of the conductor.

This offers a large exhausting surface for the charge to pass to earth. The copper conductor band is usually fixed by cleats made of the same metal. Care should be taken to keep the conductor at least 4 feet away from pipes and metal work. The steel head-gear of a pit is really a conductor in itself, but steel chimneys are sometimes fitted with a conductor to ensure the discharge being earthed quickly, and not to depend too much upon the riveted joints of the steel plates for electrical continuity. Some authorities maintain that the head-gear of all shafts should be protected by lightning conductors. There are cases on record where the sparks from atmospheric electricity, led by the wire ropes of the shaft and iron rails of the galleries, have caused explosion of fire-damp. The electrical discharge caused by lightning is practically an alternating current with a very high periodicity—much higher than that generated in practice by alternators. Strong self-induction effects are more present with high than with low periodicities. If the mains are carried overhead for any distance it is usual to protect each line with a lightning arrester before entering any building or erection.

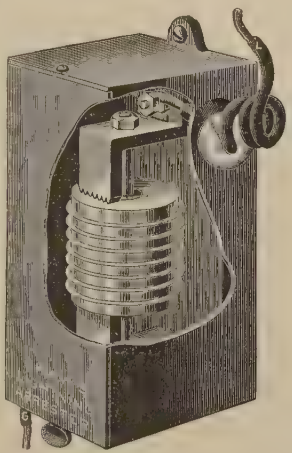


FIG. 51.—Lightning arrester.

A common form of lightning arrester consists of two copper horns; one is connected to the earth plate in the ground, the other to the supply feeder. The distance between the horns varies from 0·1 to 0·5 of an inch. A copper coil consisting of a few turns is connected to the main line before it enters the terminals of any electrical apparatus or machine. The distance between the horns is made large enough so as not to allow the electricity from the generator to bridge the gap. Should a lightning discharge take place, the electricity will not flow through the induction coil mentioned above, but will bridge across the gap to the other horn and find a ready earth. The primary object of the lightning arrester is to prevent the current in the mains from following the lightning discharge to earth. Fig. 51 shows a form of lightning arrester frequently employed at collieries.

SYSTEMS OF DISTRIBUTION

In the distribution of electrical energy there are two distinct systems in use, namely, the series system and the parallel system.

In the *Series System*, shown diagrammatically in Fig. 52, the lamps L form part of one continuous circuit. The current required is equal to that consumed by one of the lamps L, but the voltage depends upon the number of lamps used. For example, suppose we have 20 arc lamps each requiring 5 amperes at 100 volts connected up in series, the voltage required between the positive and negative mains will be $20 \times 100 = 2000$ volts, while the amperes

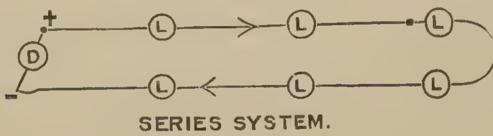


Fig. 52.

required will be only five. Thus in the series system of wiring conductors of small section may be employed, as the current to be carried is small. This system is, however, now seldom used except for arc-lamp lighting.

Parallel System.—Of this system there are several modifications.

In the system known as the two-wire parallel system, shown in Fig. 53, the lamps L and motors M are connected up across the positive (+) and negative (–) mains coming from the dynamo D.

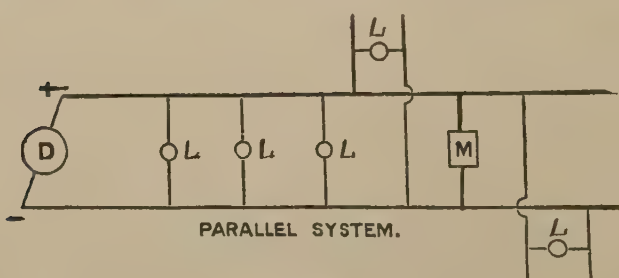


Fig. 53.

In this system the voltage is practically independent of the number of lamps and motors in the circuit, but the amperes consumed is equal to the sum of the current taken by all the lamps and motors in the system.

From this it will be seen that in the two-wire parallel system cables of large section are required, owing to the fact that the current increases with the number of lamps and motors installed.

The two-wire parallel system is very extensively adopted both

for direct current and single-phase alternating current. A combination of the series and parallel systems is sometimes adopted. For instance, with a 400-volt circuit, two lamps, each taking 200 volts, could be arranged *in series* across the mains.

Three-wire Parallel System.—This system is a modification of the two-wire system. Instead of two mains, there are three running parallel to each other. Lamps and motors are connected up from each of the outer conductors to the middle wire. In the case of motors, however, it is usual to connect up those across the two outer mains, with no connection to the middle wire at all, in order to maintain more uniform balance in the system. In a well-planned system the number of lamps between one outer and the mid-wire, and the number between the other outer and the mid-wire, should be about equal. Two generators, in series, are used in this system. The three-wire parallel system can be used with both direct and single-phase alternating currents. Its principal advantage, as compared with the two-wire system, is that for a given power slightly less copper is required.

Three-phase System.—In this system three separate mains of equal section are required. Less copper is required in the mains than in the single-phase or two-phase systems. The windings of the generators, motors, etc. may be connected up to the three conductors in two different methods. The star or Y connection is more commonly adopted, but the mesh or ▽ winding is also sometimes employed.

Sometimes a four-wire system is used with three-phase alternating current, but in the four-wire slightly more copper is required in the mains. Better regulation, however, is obtained between the phases.

Other Systems of Wiring sometimes adopted are two-phase three-wire, two-phase four-wire, and the monocyclic system.

In the two-phase three-wire system, the lamps are connected up in a similar fashion to that mentioned in the three-wire system already described. There are, however, four wires coming from the generators, two of the wires being connected together before the lamps and motors are reached.

In the two-phase four-wire system the four wires coming from the generators form two separate circuits, one for each phase. The wiring is practically equivalent to two separate parallel systems arranged side by side.

In the monocyclic system three conductors are used, but the main current is carried by two wires only, the third conductor being made to act as an auxiliary.

On this system "induction" motors are used. These are so called because the current in the armature is induced by the alternating current in the stationary coil, instead of being transmitted into the

armature coils through the commutator as in the continuous current motor.

Economy of the High-Tension System

The principal advantage of the high-tension over the low-tension system is that a considerable saving in copper may be effected. For the same power transmitted a less size of cable may be adopted. This advantage, however, is modified to some extent by the fact that the higher the tension the more expensive and elaborate must be the insulation; also greater care must be exercised in the control of the generator and cables when the high-tension system is adopted. Another advantage which can be claimed for the high-tension system is that the power can be transmitted for long distances with the minimum of loss When high-pressure current is taken into the mines it has usually to be transformed down to a lower voltage, and certain losses occur in transforming.

Hitherto, continuous current has been preferred for colliery work, but the much-debatable point as to whether alternating current is superior is now practically solved in favour of the polyphase system. Its superiority for long distance transmission, and absence of sparking in the motors, are advantages which cannot be over-estimated. It might be well to state here the definitions of *pressure* as given in the Electric Special Rules. Any voltage up to 250 in these rules is deemed *low pressure*; any voltage between 250 and 650, *medium pressure*; any voltage between 650 and 3000, *high pressure*; and any voltage above 3000, *extra high pressure.*

Colliery Electric Cables

Electric cables consist sometimes of one wire and sometimes of several wires twisted together to form a single conductor. They may be used bare, carried on insulating supports, or they may be embedded in a covering composed of one or more insulating substances.

Different substances may be employed for conducting an electric current through its circuit, those in most general use being copper, aluminium, and occasionally iron.

Of those three, copper, principally by virtue of its higher conductive power, is by far the most generally adopted. As will be readily understood by those who have carefully studied the preceding chapters of the present work, the suitability of any substance for conducting electricity is largely determined by the resistance which, for a given area, it will offer to the passage of the electric current. To cite an example which will readily appeal to the student of mining, let us for a moment liken the conductor of an electric current to the air-passages of a mine.

The resistance to the flow of air in the underground workings of a

mine varies directly as the length of the air-ways through which the air has to course, and inversely as the sectional area. For all practical purposes the same conditions hold good in connection with the flow of the electric current through a conductor; double the length of the conductor and you double the resistance, increase the sectional area of the conductor to twice its original dimensions and you lower the resistance to the passage of electricity to only half of what it at first was.

Again, the resistance to the flow of air in an air-way varies with the nature and condition of the roads, and in the same way the resistance to the passage of an electric current depends upon the nature of the conductor through which it is made to flow.

Silver possesses the highest conductivity of any substance, but, on account of its prohibitive price, is never used as an electrical conductor.

Copper comes next in point of conductive power. Aluminium has only about five-eighths of the conductivity of copper; although at present prices it about equals copper wire as an electrical conductor. Iron wire, which is also sometimes used as an electrical conductor, has a very low conductivity, but possesses the advantage of being much cheaper than either aluminium or copper. The specific resistance of any substance is standardised as the resistance due to a length of 1 centimetre with a sectional area of 1 square centimetre, at the temperature of zero. It is usually expressed in microhms when dealing with metallic conductors, and in ohms when speaking of liquids.

The following table gives approximately the relative resistances and also the specific gravities of copper, aluminium, and iron :—

	Specific Resistance.	Specific Gravity.
Copper	1·565	8·89
Aluminium . . .	2·635	2·65
Iron	9·068	7·80

The figures given, although they do not perhaps represent the precise value of any of the metals,—those values varying somewhat, of course, with the different processes adopted in the manufacture of the substances,—may be taken to indicate the *average* values in each case.

It will be seen from the table that copper has nearly double the current-carrying capacity of aluminium,—the specific resistance of the former being little more than half the specific resistance of the latter,—and that it has about six times the conductive power of iron.

In the case of aluminium, however, it should be noticed that its specific gravity is only about two-sevenths of the weight of copper.

This means that, for equal weights, aluminium would have $\left(\frac{1{\cdot}565}{2{\cdot}635} \times \frac{8{\cdot}89}{2{\cdot}65}\right) = 1{\cdot}97$ times the current-carrying capacity of copper; its area, on the other hand, would be $\left(\frac{8{\cdot}89}{2{\cdot}65}\right) = 3{\cdot}35$ times the area of the copper wire of the same weight.

Again, for equal conductivity, aluminium has only about four-sevenths of the tensile strength of copper, and this fact also accentuates its unsuitability for certain purposes. Iron has, of course, a much higher tensile strength than copper, being approximately about one and two-third times stronger than the latter in ultimate strength.

The following table gives the tensile strength, conductivity, specific gravity, etc., of various metals used as electrical conductors :—

TENSILE STRENGTH, ETC., OF VARIOUS ELECTRICAL CONDUCTORS [1]

Material.	Conductivity, pure soft Copper = 100.	Specific Gravity.	Conductivity for Equal Weights.	Tensile Strength.
Copper, hard drawn . .	97	8·9	97	60,000 lbs.
Aluminium, hard drawn .	59	2·7	194	28,000 ,,
Steel wire (for ropes) .	10·5	7·85	12	140,000 ,,
Galvanised iron wire .	14	7·7	16	56,000 ,,
Aluminium bronze . .	about 50	3·5	127	63,000 ,,
Silicon bronze . . .	(?) 97	8·9	97	63,000 ,,

Galvanised iron wire is very often used on electrical signalling circuits. The current on such circuits being, of course, very small, the iron conductor may be used of a sufficient size to give a comparatively low resistance, and yet not be too large for convenient handling.

The price of iron wire is very much less than the price of either aluminium or copper, and, in point of cost, for small currents is of course very much cheaper.

Even for large currents the bare iron conductor is considerably cheaper than the uninsulated aluminium or copper conductor for an equal conductivity.

When we come to consider the relative advantages of insulated conductors of iron, aluminium, or copper, however, the comparison assumes a very different aspect.

For the same conductivity, both iron and aluminium, having to be of greater area than copper, the cost of covering the conductor with insulating material is higher for the two first-named materials than it is for the last-mentioned. Thus, although the price of copper and

[1] Whittaker's *Electrical Engineer's Pocket Book.*

aluminium is about the same for conductors of equal current-carrying capacity, the cost of insulating the copper conductor would be so much less than the cost of insulating the aluminium conductor, that the price for copper cables would ultimately work out at a cheaper rate than would the aluminium cable.

In the case of the iron conductor, the cost of insulation, owing to the large size of cable necessary, would be absolutely prohibitive.

For overhead transmission of power, aluminium bids fair to become a formidable rival to the copper cable, as for such work the conductor need not be insulated, but may be carried bare on insulating supports.

One noteworthy drawback to the employment of aluminium cables for aerial lines is the difficulty of making efficient joints. Satisfactory results are, however, now said to be obtained by means of the M'Intyre joint, which consists in inserting the two ends to be connected into an oval tube of aluminium. This tube is given two or three complete twists, and the two ends are then securely clamped. Other joints, mechanical, soldered, and electrically welded have also been tried with occasional success.

To find the total resistance of an electrical conductor of any given length or size, the following formula is adopted :—

$$\left.\begin{array}{l}\text{Total resistance in}\\ \text{microhms}\end{array}\right\} = \frac{\text{specific resistance} \times \text{length in centimetres}}{\text{area in square centimetres}},$$

$$\text{or } \frac{\text{specific resistance} \times \text{length in feet} \times 30{\cdot}4799}{\text{area in square inches} \times 6{\cdot}4516},$$

because there are 30·4799 centimetres in a British lineal foot, and 6·4516 square centimetres in a standard square inch. In order to have the answer in ohms, the result obtained by either of the above formulæ would have to be further divided by 1,000,000, because a microhm is the $\frac{1}{1000000}$th part of an ohm.

The formulæ may be simplified to the following :—

$$\frac{\text{Length in feet} \times \text{specific resistance} \times 0{\cdot}0000047}{\text{Area in square inches}} = \left\{\begin{array}{l}\text{total resistance}\\ \quad\text{in ohms.}\end{array}\right.$$

Copper cables generally consist of a number of strands of wire twisted together to form a single conductor.

Sizes of Cables

The wires which make up the ordinary copper cable are all drawn to a certain legalised standard wire gauge, known by the initials S.W.G. Thus any wire of a certain definite sectional area will be found to coincide with a certain number in the standard wire gauge. The following table will suffice to show how the wires are gradationed,

and how each wire is known, not so much by its size, but by the number in the S.W.G. with which it is identified :—

British Standard Wire Gauge

Single Conductors

Size. S.W.G.	Diameter.	Nominal Sectional Area.	Size. S.W.G.	Diameter.	Nominal Sectional Area.
7/0	·500	·1963	12	·104	·00849
6/0	·464	·1691	13	·092	·0066
5/0	·432	.1466	14	·080	·005
4/0	·400	·1257	15	·072	·004
			16	·064	·0032
3/0	·372	·1087	17	·056	·0024
2/0	·348	·09511			
1/0	·324	·08245	18	·048	·0018
1	·300	·07069	19	·040	·00125
2	·276	·05983	20	·036	·001
			21	·032	·0008
3	·252	·04988	22	·028	·0006
4	·232	·04227			
5	·212	·03530	23	·024	·0004524
6	·192	·02895	24	·022	·00038
7	·176	·02433	25	·020	·0003142
8	·160	·02011	26	·018	·0002545
9	·144	·01629	27	·0164	·0002112
			28	·0148	·000172
10	·128	·01287	29	·0136	·000145
11	·116	·01057	30	·0124	·00012

From this table it will be seen that No. 1/0 S.W.G. means a copper wire 0·324 inch in diameter and 0·08245 square inch in area, that a No. 30 wire S.W.G. is 0·0124 inch in diameter, and that all the other intermediate sizes are numbered progressively.

A number of wires twisted together to form a single cable is denominated in the standard wire gauge by such numbers as 19/16, which means that the cable is composed of 19 wires of No. 16 S.W.G., or as 7/10, which means 7 wires of No. 10 S.W.G. The wires are twisted into strands of 3, 7, 19, 37, 61, or 91 separate wires. The greater the number of wires for a given thickness of strand the more flexible is the cable.

The sectional area of conductor necessary is determined either by the safe current density, or by the loss of volts allowable. A current density of 1000 amperes per square inch is generally considered

safe for estimating upon, but this may be increased or decreased according to circumstances. As the sectional area varies inversely to the current density, the calculation is easily made. For instance, if a 1 square inch cable is suitable for 1000 amperes, then a 0·5 square inch cable is approximately suitable for 500 amperes; or a 1·5 square inch cable is approximately suitable for 1500 amperes.

Again, where a current density of 800 amperes per square inch is used, a 1 square inch cable is suitable for 800 amperes; then a 0·5 square inch cable is approximately suitable for 400 amperes; or a 1·5 square inch cable is approximately suitable for 1200 amperes.

When it is necessary to estimate the size of cable for a given loss of power, the following formulæ will give areas:—

For Continuous and Single-Phase Alternating Currents—

$$\text{Area in square inches} = \frac{\text{amps.} \times \text{lead and return in yards}}{\text{loss in volts} \times 40{,}000 \text{ (Constant)}}.$$

For Two-Phase Alternating—

$$\text{Area in square inches} = \frac{\text{amps.} \times \text{length (one direction)}}{\text{loss in volts} \div 2 \times 40{,}000 \text{ (Constant)}}.$$

For Three-Phase Alternating—

$$\text{Area in square inches} = \frac{\text{amps.} \times \text{length (one direction)}}{\text{loss in volts} \div 1{\cdot}73 \times 40{,}000 \text{ (Constant)}}.$$

The above formulæ only apply in the case of alternating currents up to about 0·4 square inch. Above that there is another slight loss, due to what is known as skin effect, which increases with the size of cable.

An alternative method (and one that is more conveniently remembered) for approximately calculating the size of three-phase conductors is to work out the total section of copper required for the same power and loss, on the continuous current two-wire system, and to divide this total by three. This gives the sectional area per conductor, with a power factor of about 0·8.[1]

Areas of Neutral Conductors or Common Returns are usually taken as follows:—Three-wire system: neutral conductor one-half to one-third the section of either outer, depending upon balancing effect of load.

Two-phase three-wire: common return 1·41 time the section of either outer.

Two-phase four-wire: all conductors same section.

Three-phase four-wire neutral conductor: practice varies from one-half the area of an outer, to the same section as outer, depending upon balancing effect of load (Glover).

[1] *Power Factor* is a term used in connection with alternating current in order to express the effect of the lagging of the current, which creates a slight difference between the true watts and the apparent volt-amperes.

Current Density in Cables

The current density in an insulated copper cable is generally limited to the rate of 1000 amperes per square inch, for currents up to 200 amperes. For larger currents than 200 amperes, the current density permissible decreases to some extent, owing to the increased difficulty in large cables of dissipating the heat generated by the flowing current. Aluminium cables are limited to a current density of from 500 to 600 amperes per square inch.

A current density of 1000 amperes per square inch means that a cable must have a sectional area of one square inch in order to carry safely a current of 1000 amperes. The amperes allowable in cables of smaller section vary in direct proportion as the size of the conductor.

As already mentioned, however, in practice the larger the size of cable, the lower its rate of conductivity.

The necessity for prescribing a certain maximum current density in an electrical conductor arises from the fact that a current of electricity in passing through a conductor generates heat, and if the heat is excessive the temperature may become so great as to injure the insulation, or to damage the cable itself by expansion. By limiting the current density to a safe maximum these dangers are avoided.

Loss of Pressure in Cables

In overcoming the resistance of a conductor a percentage of the pressure on a circuit is lost. From Ohm's law we learn that $C \times R = E$, where E is the pressure in volts, C the current in amperes, and R the resistance in ohms. Now by this rule we may calculate the pressure drop in a cable in the following way:—

Current in amperes × resistance in ohms = volts lost in transmission.

The pressure drop in a cable thus varies directly as the product of the amperes and the ohms, or of C and R in Ohm's law.

It is independent of the voltage, and therefore as the voltage increases the percentage of loss in a cable decreases. For this reason it is more economical in respect to the cost of conductors to use a current of high voltage and low amperage than one of low voltage and high amperage.

The loss of pressure in a cable is, of course, directly proportional to the length, because, as we have already seen, the resistance of a conductor increases directly as the length increases.

To find the loss of energy in watts and in horse-power, the following formulæ are used:—

Drop in volts × amperes = loss in watts.

$$\frac{C^2R}{746} = \text{loss of energy in horse-power.}$$

For a density of 1000 amperes per square inch, the voltage drop in a cable is about $2\frac{1}{2}$ volts per 100 yards, and for a density of 800 amperes about 2 volts per 100 yards.

In an actual case noted by the authors, the voltage drop was 26 volts, with a working pressure of 420 volts at the generator and a density of 800 amperes per square inch in the cable. The distance from the surface generator to the motor was about 1200 yards. After the temperature of the cable, through which a current of electricity is flowing, has reached a certain point (60° F. or $15\frac{1}{2}$° C.) the volts lost increase by about 4 per cent. for every further rise of 10° C. or 18° F.

The following table, prepared from the list of Messrs. W. T. Glover & Co., manufacturers of colliery cables, gives details of copper-stranded conductors:—

Details of Copper-Stranded Conductors

Size.	Amperes at 1000 per Square Inch.	Diameter of each Wire.	Diameter of Strand.	Nominal Sectional Area, viz., Area of Solid Wire having same Conductivity.	Maximum Resistance at 60° Fahr.	Minimum Weight.
S.W.G.		Ins.	Inches.	Sq. Inches.	Ohms per 1000 Yards.	Lbs. per 1000 Yards.
3/25	0·924	·020	·043	·000924	26·53	10·90
3/24	1·118	·022	·047	·001118	21·93	13·18
3/23	1·330	·024	·052	·001330	18·43	15·69
3/22	1·812	·028	·060	·001812	13·54	21·35
3/21	2·366	·032	·069	·002366	10·36	27·88
3/20	2·994	·036	·078	·002994	8·19	35·30
3/19	3·697	·040	·086	·003697	6·63	43·58
3/18	5·323	·048	·103	·005323	4·61	62·74
7/25	2·162	·020	·060	·002162	11·34	25·35
7/24	2·616	·022	·066	·002616	9·37	30·66
7/23	3·114	·024	·072	·003114	7·88	36·50
7/22	4·238	·028	·084	·004238	5·79	49·69
7/21½	4·864	·030	·090	·004864	5·04	57·03
7/21	5·535	·032	·096	·005535	4·43	64·89
7/20½	5·869	·033	·099	·005869	4·16	69·00
7/20	7·005	·036	·108	·007005	3·50	82·13
7/19	8·649	·040	·120	·008649	2·84	101·4
7/18	12·46	·048	·144	·01246	1·97	146·0

DETAILS OF COPPER-STRANDED CONDUCTORS—(*continued*).

Size.	Amperes at 1000 per Square Inch.	Diameter of each Wire.	Diameter of Strand.	Nominal Sectional Area, viz., Area of Solid Wire having same Conductivity.	Maximum Resistance at 60° Fahr.	Minimum Weight.
S.W.G.		Ins.	Inches.	Sq. Inches.	Ohms per 1000 Yards.	Lbs. per 1000 Yards.
7/17	16·95	·056	·168	·01695	1·45	198·7
7/16	22·14	·064	·192	·02214	1·11	259·5
7/·068″	25·00	·068	·204	·02500	·9810	293
7/15	28·03	·072	·216	·02803	·8750	328
7/14	34·59	·080	·240	·03459	·7088	406
7/13	45·75	·092	·276	·04575	·5360	536
7/·095″	50·00	·095	·285	·05000	·5027	572
7/12	58·46	·104	·312	·05846	·4195	685
7/11	72·75	·116	·348	·07275	·3371	853
7/10	88·58	·128	·384	·08858	·2769	1038
7/9	112·12	·144	·432	·11212	·2188	1314
7/8	138·40	·160	·480	·13840	·1773	1622
7/6	199·24	·192	·576	·19924	·1231	2336
19/22	11·49	·028	·140	·01149	2·135	135
19/21	15·00	·032	·160	·01500	1·635	176·4
19/20	18·99	·036	·180	·01899	1·292	223
19/19	23·43	·040	·200	·02343	1·046	276
19/18	33·75	·048	·240	·03375	·7267	397
19/17	45·93	·056	·280	·04593	·5339	540
19/·058″	50·00	·058	·290	·05000	·4977	580
19/16	60·00	·064	·320	·06000	·4087	706
19/15	75·86	·072	·360	·07586	·3130	893
19/14	93·72	·080	·400	·09372	·2616	1103
19/·082″	100·00	·082	·410	·10000	·2490	1158
19/13	125·00	·092	·460	·12500	·1978	1458
19/·101″	150·00	·101	·505	·15000	·1640	1757
19/12	158·26	·104	·520	·15826	·1490	1864
19/11	197·10	·116	·580	·19710	·1244	2319
19/10	239·99	·128	·640	·23999	·1022	2823
37/20	36·95	·036	·252	·03695	·6637	434·9
37/19	45·62	·040	·280	·04562	·5376	537·1
37/18	65·69	·048	·336	·06569	·3733	773·3
37/17	89·39	·056	·392	·08939	·2743	1052·8
37/16	116·8	·064	·448	·11680	·2100	1375

DETAILS OF COPPER-STRANDED CONDUCTORS—(*continued*).

Size.	Amperes at 1000 per Square Inch.	Diameter of each Wire.	Diameter of Strand.	Nominal Sectional Area, viz., Area of Solid Wire having same Conductivity.	Maximum Resistance at 60° Fahr.	Minimum Weight.
S.W.G.		Ins.	Inches.	Sq. Inches.	Ohms per 1000 Yards.	Lbs. per 1000 Yards.
37/15	150·0	·072	·504	·15000	·1660	1740
37/14	182·4	·080	·560	·18240	·1344	2148
37/·082″	200·0	·082	·574	·20000	·1280	2257
37/13	250·0	·092	·644	·25000	·1016	2842
37/·101″	300·0	·101	·707	·30000	·0843	3424
37/12	308·3	·104	·728	·30832	·0795	3631
37/·110″	350·0	·110	·770	·35000	·0711	4062
37/·118″	400·0	·118	·826	·40000	·0618	4674
61/18	108·3	·048	·432	·10828	·2265	1275
61/17	147·3	·056	·504	·14734	·1664	1736
61/16	192·5	·064	·576	·19245	·1274	2267
61/15	243·6	·072	·648	·24360	·1007	2870
61/14	300·7	·080	·720	·30073	·0815	3543
61/13	400·0	·092	·828	·40000	·0617	4685
61/·098″	450·0	·098	·882	·45000	·0543	5317
61/·101″	500·0	·101	·909	·50000	·0512	5647
61/12	508·2	·104	·936	·50820	·0483	5987
61/·108″	550·0	·108	·972	·55000	·0447	6456
61/·110″	600·0	·110	·990	·60000	·0431	6699
61/·118″	650·0	·118	1·062	·65000	·0375	7708
91/14	448·6	·080	·880	·44859	·0547	5286
91/13	600·0	·092	1·012	·60000	·0421	6854
91/·098″	700·0	·098	1·078	·70000	·0364	7932
91/·101″	750·0	·101	1·111	·75000	·0343	8425
91/12	800·0	·104	1·144	·80000	·0323	8933
91/·110″	900·0	·110	1·210	·90000	·0289	9993
91/11	943·2	·116	1·276	·94322	·0260	11117
91/·118″	1000·0	·118	1·298	1·000	·0251	11500
127/·101″	1000·0	·101	1·313	1·000	·0246	11760

Insulation of Cables

Where it is impossible to carry the bare conductors on insulating supports with a comfortable degree of safety, it becomes necessary to cover the cables throughout their entire length with some protecting and insulating material.

Various materials are used for this purpose, the most commonly employed being bitumen, pure and vulcanised rubber, specially prepared paper, and impregnated jute.

Material suitable for insulating a cable is usually known by the term "di-electric." The strength of a di-electric is measured by the resistance which it is capable of offering to the passage of an electric current. The thickness of the insulation of a cable must, of course, be suited to the voltage that it is required to carry.

For high-voltage distribution it is usual to allow from $\frac{1}{15}$th to $\frac{1}{20}$th inch per 1000 volts. On a 5000-volt circuit the thickness of the insulation would thus require to be about $\frac{1}{4}$ inch—that is to say, a concentric circle of insulation, $\frac{1}{4}$ inch deep, would have to be placed round the copper conductors.

Of course much depends upon the di-electric strength of the insulating material used, and also upon the size of the conductor.

The outside diameter of, say, a $\frac{1}{2}$ inch copper cable insulated as above would be $\frac{1}{2}+\frac{1}{4}+\frac{1}{4}=1$ inch, plus the usual protective covering, such as lead sheathing or braiding.

For low-voltage distribution the thickness of the insulation is slightly decreased. The thickness of the insulation is increased as the thickness of the copper cable or conductor increases. For instance, the thickness of insulation for a 37/12 cable is just about double that for a 7/20 cable, a tension of 500 volts being employed in each case.

Protecting the Insulation

Cables are generally protected by some covering in addition to the insulation. Sometimes they are coated with jute fibre, made waterproof, and sometimes wrapped round with steel tape coated with some waterproofing compound, and having a covering of jute fibre, soaked in tar, braided over.

For protecting cables in very wet situations, they are frequently cased in lead.

To prevent abrasion, steel wire armouring is also employed, the steel wire being wrapped spiral fashion round the cable. Lead coverings and wire armouring should always be earthed, and made continuous throughout their entire length.

Some objections to wire armouring are discussed in Chapter XIV.

Types of Cables used in Collieries

The types of cables generally used in colleries are the following:
1. Single cables, for continuous current.
2. Twin cables, for continuous current and single-phase alternating current.

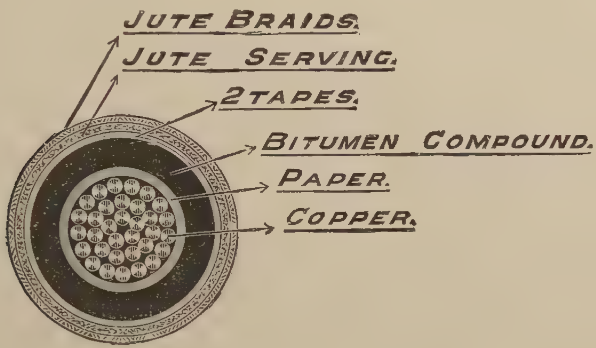


Fig. 54.—Single-core cable.

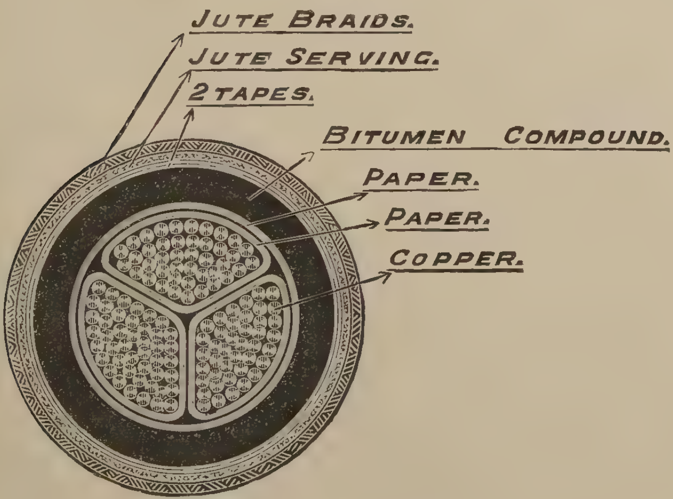


Fig. 55.—Three-core cable.

3. Three-core cables, for three-phase alternating current.
4. Concentric cables, continuous current or single-phase.

Fig. 54 shows a single cable, insulated with impregnated paper, and sheathed with bitumen.

Fig. 55 shows a three-core cable, also insulated with paper, and sheathed with bitumen.

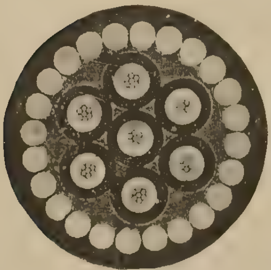


Fig. 56.—Seven-core conductor.

The concentric type of cable cannot be recommended for colliery work, and is now very little used.

The above types of cables are manufactured by Messrs. Glover of Manchester, who have had great experience in the laying down of cables in mines.

A seven-core cable made by the Helsby Cable Company is illustrated in Fig. 56. This class of cable is sometimes used in signalling and telephone circuits.

Suspension of Cables in Shafts

The lowering and fixing of a cable in a shaft calls for very careful and cautious dealing, and should never be entrusted to careless or inexperienced workmen. Frequently the makers of the cables to be installed are also asked to undertake the lowering and fixing, and the task is generally completed with greater satisfaction to all concerned than if the management had undertaken the work unaided. One of the best methods of lowering the cable is to take the drum carrying the cable on the cage, fasten one end of the cable to any suitable part of the pithead structure, and then unwind the cable from the drum as the cage slowly descends. The cable is cleated at suitable intervals down the shaft. By this method there is little or no strain put on the cable.

Sometimes the drum is fixed at the top, and the cable unwound and lowered down the shaft. One of the dangers in this method is that, unless very efficient braking is possible, the weight of the cable may become so great as to get beyond control. It is therefore only suitable for lowering light cables in shallow shafts, or where the cable is in lengths, in a deep shaft, it may be employed in lowering the top length to the first joint-box, but should be well braked, and the cable run over a large diameter pulley with grooved face. Another method is to pull the cable from the bottom of the shaft up to the top before clamping. Of course in this method great strain is put on the cable, as it has its whole weight to bear till cleated.

Fixing of Cables in Shafts

There are various methods in use of fixing cables down the shaft. A common plan is to fix the cables to the buntons by means of wood cleats, at intervals of 5 to 50 yards.

In this method the cable has to bear the strain of its own weight between each pair of cleats. It is, however, a simple and inexpensive method, and is often adopted.

Another method is to fix the cables down the whole length of the shaft in a spiral or zigzag grooved casing of wood. One method of cleating is shown in Fig. 57.

In wet shafts the cables are sometimes fixed solid in the spiral or zigzag casing mentioned above. The casing and cable are then treated with a heavy coating of Stockholm tar, the cover screwed on, and a coating of tar given to it also. This method has given very satisfactory results under the most trying conditions.

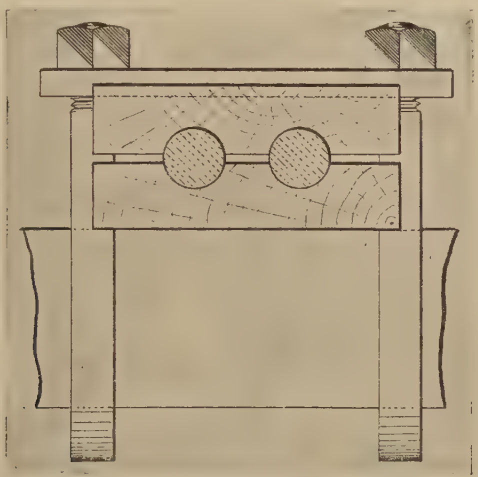


FIG. 57.—Method of cleating cables to shaft girders.

A somewhat similar method to this was used at the Parton Collieries, Whitehaven, the only difference being that the casing carrying the cable was not zigzagged, and was filled with bitumen instead of being simply tarred. The shaft is very wet, but no leakage has yet occurred. Sometimes the cable is suspended from the pithead, with no intermediate clamp or support whatever.

Fig. 58 illustrates the method of suspending armoured cables from the shaft-top. The wires of the armouring are bent back and clamped tightly in a steel hanger. By means of chain slings attached to the projections on the hanger the cables are suspended. This method, of course, has its limits, owing to the weight of the cable being practically unsupported throughout its entire length, save at

the top. It should never be employed for any greater depth than, say, 200 yards.

Another method of supporting cables down the shaft is shown in Fig. 59. The cable is placed in a sheath or cleat of oak or elm, which is glanded together as shown. From the centre gland the cleats are supported by chains carried on hooked rag bolts let into the brickwork.

Jointing of Cables in Shafts

Where possible, jointing of cables in shafts should be carefully avoided. Sometimes, however, it is found impossible to avoid jointing,

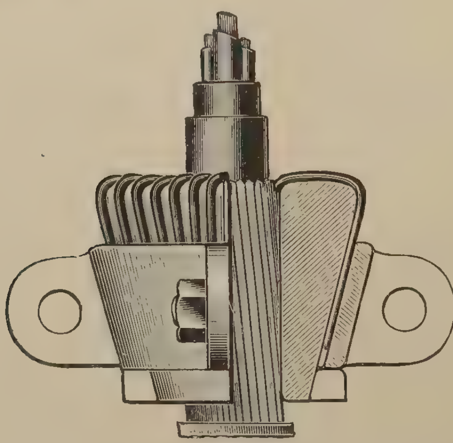


Fig. 58.—Method of suspending armoured cables from top of shaft.

as in deep shafts, where the weight of an unbroken cable would be enormous, and perhaps unmanageable.

One of the best methods of jointing is the following:—

A chamber or recess is made in the side of the shaft, and in this chamber the joint-box is placed. This method necessitates tinkering with the shaft walls, however, which makes it often impracticable. Where exposed joints cannot be avoided, care must be taken to have the joint-box suspended in such a way that no strain is put on the actual joint.

Suspension of Cables in Roadways

Where the cables are to be suspended along the sides of the road, they must be hung in such a manner that no damage can be done to

them by falls of roof or sides. A good method is to hang the cable by means of leather suspenders, as shown in Fig. 60, at intervals of, say, from 3 to 10 yards.

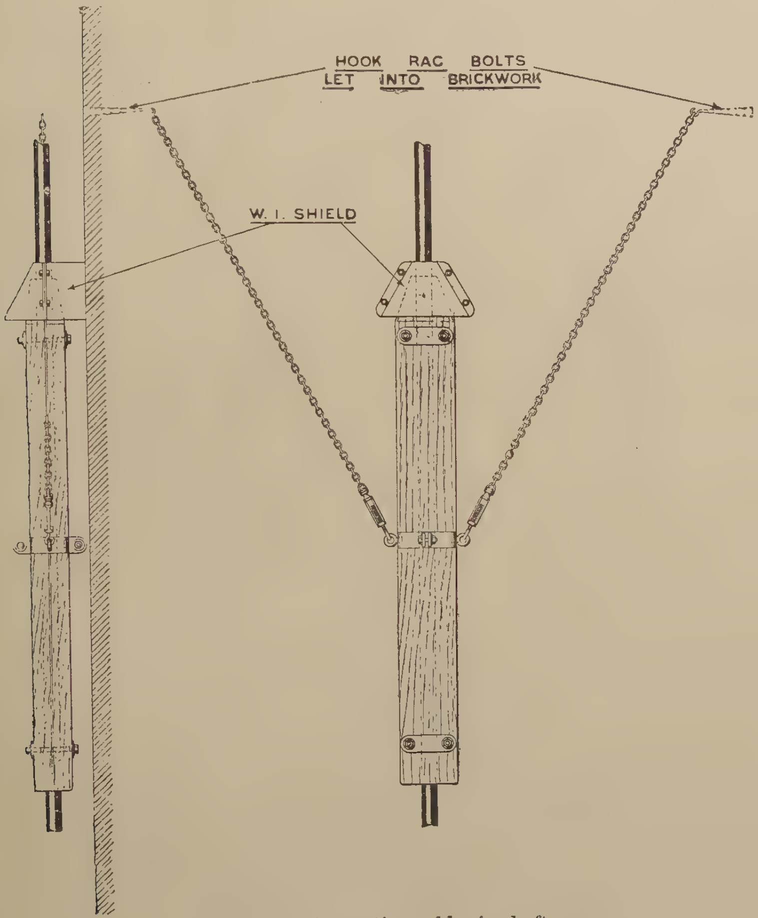


Fig. 59.—Supporting cables in shaft.

Another plan is to run the cable on roller insulators, as illustrated in Fig. 61.

When the cable is depressed at any point, the rollers turn with the travel of the cable in that direction, and there is generally enough

slack between the rollers to allow depression to take place even to the floor of the seam without any straining of the cable.

Callender's Cable Clip or Suspender

This type of cable suspender is designed to meet the requirements of the Special Rules for the Installation and Use of Electricity in Mines, which say that "cables underground, when suspended, shall be suspended by leather or other flexible material in such a manner as to allow of their readily breaking away when struck, before the cables themselves can be seriously damaged."

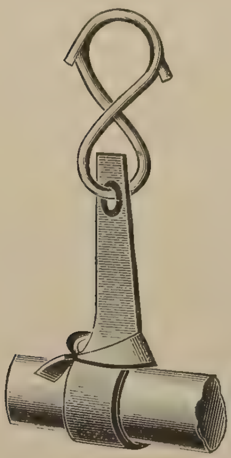


Fig. 60.

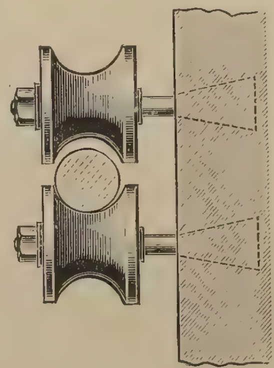


Fig. 61.

It may readily be seen from the accompanying illustration (Fig. 62) that Callender's suspender eminently fulfils the above requirements. It forms an efficient support, and at the same time offers a comparatively slight resistance to the breaking away of the cable should a fall occur.

The illustration gives several views of the clip. By means of the spiked fastening the suspender is readily secured to the roof or side timber.

Joint-Boxes

Wherever joints have to be made, suitable joint-boxes should be used.

The space between the box and the cables should in every case be filled solid with diatrine or other suitable insulating material.

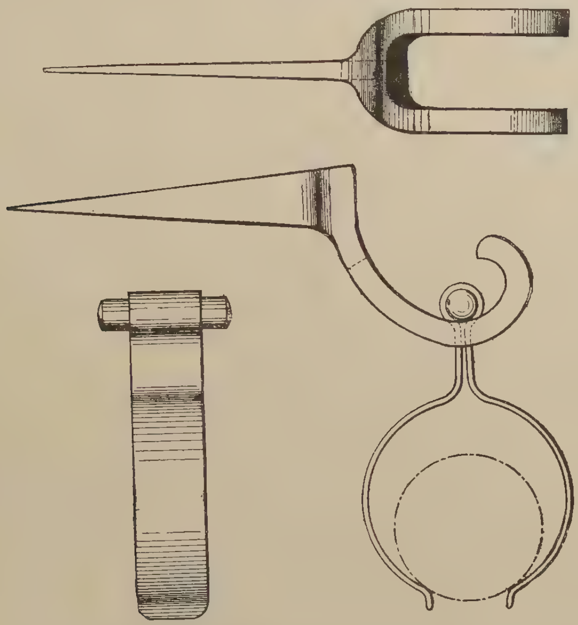


FIG. 62.—Spring clip for suspending cables.

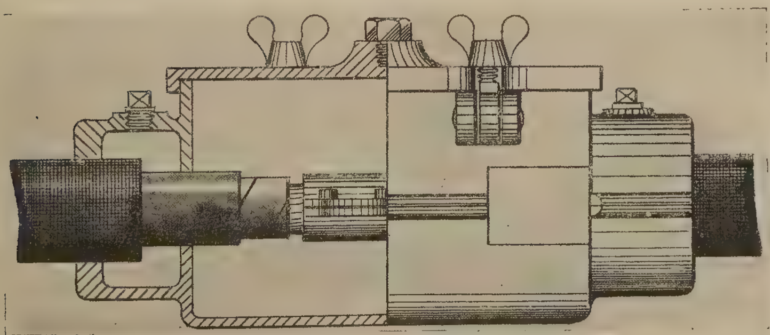


FIG. 63.—Straight-through joint-box, for single conductor cables.

Fig. 63 shows a straight-through joint-box for single conductor cables, made by Messrs. W. T. Glover.

Disconnecting Boxes

Disconnecting joint-boxes should be used where the current has to be conveyed a considerable distance into the workings. By employing these, the circuit is split up into sections of, say, $\frac{1}{4}$ mile, fault-finding is rendered easier, and extensive breakdowns reduced to a minimum.

The plan of a three-way disconnecting joint-box for three-core cables, made by Messrs. W. T. Glover, is shown in Fig. 64.

Fig. 65 shows a disconnecting straight-through joint-box, designed by the Callender Company. The cast-iron box surrounding the joint

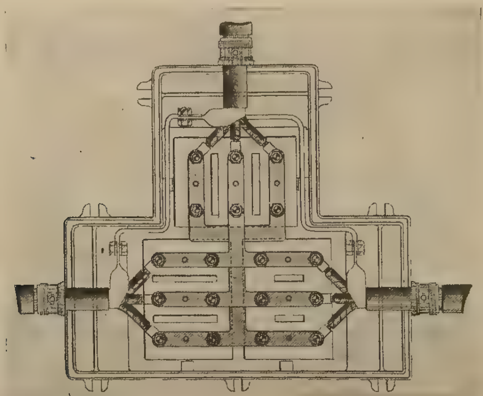


Fig. 64.—Plan of three-way disconnecting joint-box, for three-core cables.

is made water-tight and gas-tight, the top cover being bolted down on a rubber joint, and the glands at the cable ends lead-sealed.

The terminal connections are carried on a teak base, mounted on porcelain supports. The lower half of the box is filled with insulating compound, and the top portion, up to the cover, with oil. The armouring of the cables is clamped to the box so as to maintain its continuity.

Solid System or Troughing

Sometimes it is preferred to carry the cables in specially prepared troughing instead of suspending them at the side of the roadway.

Fig. 66 shows a method of troughing in which three single vulcanised bitumen cables are laid solid in a cast-iron trough.

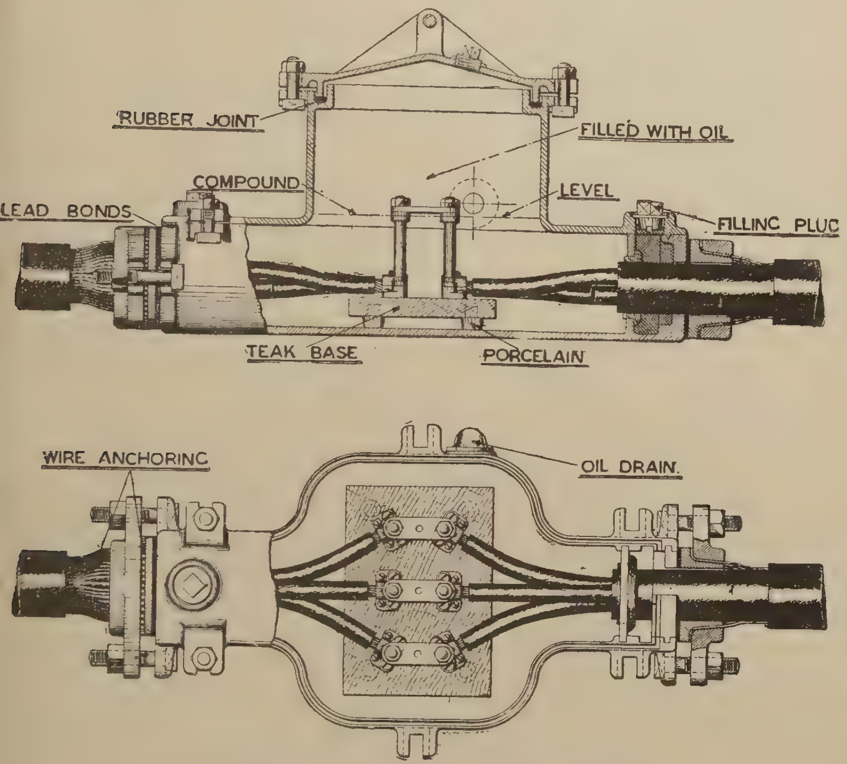


Fig. 65.—Disconnecting straight-through joint-box.

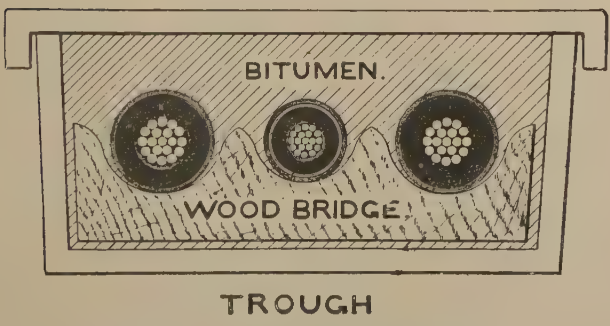


Fig. 66.—Cables in cast-iron trough.

The cables rest in the grooves of a specially designed wood-bridge, and the trough is filled solid with bitumen.

Another method is by wood troughing.

Fig. 67 shows a three-core cable in wood troughing. The wood troughs are treated with Stockholm tar as a means of preservation. As in the cast-iron troughing, the cables are carried in a wood-bridge, and laid in bitumen. The cover of the troughing is of tile.

Fig. 68 shows the method of jointing the wood trough. The above methods of troughing are adopted by the Callender Cable Company.

The Howard Asphalt System

In this system of troughing bridge pieces are dispensed with. The cables are laid on the bottom of an asphalt trough, and are then filled in solid with bitumen, asphaltic concrete being afterwards poured

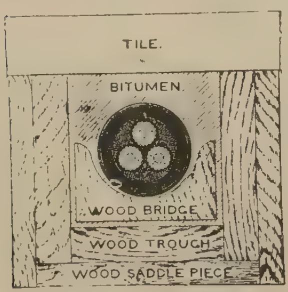


Fig. 67.—Three-core cable in wood trough.

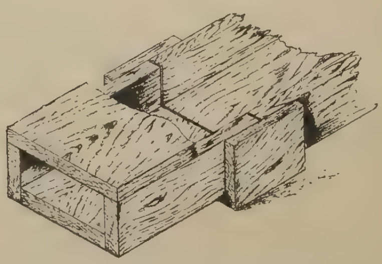


Fig. 68.—Method of jointing wood troughs.

over the whole. The principal advantage of the asphalt trough is that it possesses considerable flexibility, which enables it to move with any subsidence of the ground on the surface, or upheaval of the floor of a seam underground. It is also impervious to water or acids.

The solid system is also sometimes adopted for surface mains where the power station is situated a considerable distance from the mine.

In such circumstances, another plan is to run the cable on porcelain insulators fixed on wood or metal poles firmly fixed in the ground.

The Simplex System

It is now generally accepted that one of the best methods of supporting and protecting electrical conductors for electric light and power distribution is by stout steel or iron tubes, especially in such

places as mines and collieries where there is risk of conductors being subjected to rough usage and the attacks of moisture. Screwed steel tube or conduit is often adopted in such places, the whole system being made electrically continuous, and connected to earth. The tubes and fittings should be well protected from rust and corrosion either by a thin coating of high-class enamel (such as is employed on all Simplex conduits and fittings) or, in extreme cases, by galvanising. Important points that should be observed are :—

1. The selection of the type of conduit. As choice lies only with screwed heavy-gauge types, the final selection is limited to three grades: "Wireduct" (welded), screwed brazed, and solid drawn. The names are descriptive of the nature of the tubes, and of the three the latter is to be preferred. It is the highest class of tube, and is readily bent cold, thus effecting some saving in accessaries. If cost is a consideration, "Wireduct" is the cheapest, but, although of good quality, is sold at a price which does not permit of the makers giving any guarantee. Screwed brazed is a grade between these two in price and quality.

2. The fittings for use with these conduits will, of course, also be screwed; they comprise bends, couplings, tees, and junction boxes; the bends used should, wherever possible, be of the "normal" type, so as to give as large sweep when drawing through cables as possible. If room does not permit of using a large bend, then an inspection bend, fitted with a heavy cast sunk cover and made water-tight, will be found most satisfactory. In fact, it is advisable to adopt this type of cover throughout for all inspection and junction boxes, as they permit of making the box water-tight, which is a most desirable feature in mining installations.

It is necessary, of course, that all iron fittings employed for electric wiring work should be perfectly smooth inside, and have no sharp internal projection or corners likely to damage the braiding of the cables, and they should be protected from rust in the same way as the conduit.

Lamp Fittings.—If the water-tight principle is being adopted for running the conduits, to make a satisfactory job it is necessary to extend the same to the lamp fittings. There are on the market a number of patterns of pendants, brackets, etc., of satisfactory design for accomplishing this, and they are also strongly made so as to be suitable for the rough condition of colliery installations. Switches, plugs, cut-outs, etc. are also manufactured in the iron-clad pattern.

Wiring.—The actual installation of the wires may be carried out in two ways: (1) Threading through; (2) drawing through. With screwed conduits and fittings the first method should not be adopted, owing to the unavoidable twisting of the cables when screwing up. The second method is far preferable; the whole of the conduits

should as far as possible be connected up and erected, leaving fish wires in, and the cable drawn through by means of these afterwards. By means of a plentiful use of draw-in boxes in long runs, and other convenient inspection openings at places where there are bends in the tube, this operation is rendered perfectly easy. Generally speaking, about 40 feet in a straight run is the maximum distance which a fish wire can be pushed through under ordinary conditions, and inspection boxes should not be farther apart than this distance.

CHAPTER IV

PRIME MOVERS

Introductory: the steam engine—Corliss—Trip gear—High speed—Steam-engine indicator—Indicated horse-power—Brake horse-power—Comparisons between single, compound, and triple-expansion engines—Transmission of power by belting, ropes, etc.—Steam turbines: Parsons, De Laval, Curtis, Rateau—Gas and oil engines—Water-power—Single and double vortex turbines—Pelton wheel.

In the economic generation of electricity it is obvious that very much must depend upon the economy and efficiency of the prime mover adopted for the driving of the dynamo.

If the motive power lacks in efficiency or economy, it is evident that the inefficiency of the dynamo will be greatly accentuated thereby.

To obtain not only satisfactory results, therefore, but also to give the modern electric generator a fair opportunity to prove its undoubted excellency, it is absolutely essential that the very best type of the modern prime mover should be adopted.

But the question arises, what is the most efficient type of prime mover that modern invention and first-class workmanship can place at our service?

In attempting to answer this query it must be recognised that much depends upon the circumstances of the case.

For example, if water-power is available in sufficient quantities, there can be no question as to how the dynamo is to be driven. We have at our command a practically inexhaustible source of power supply, costing little or nothing, and yielding a never varying and always available potential.

Beyond the initial outlay incurred in the installation of the vortex turbine or Pelton wheel, or both, there would be no expenditure whatever, and the working expenses so far as the prime mover is concerned would be of little account. Where water-power is not obtainable, the question as to what is the most economic source of power is more difficult to answer.

Steam power has for long held undisputed possession for colliery work in general, as well as in the generation of electric current supply,

and although other sources of power, such as gas and oil, are now coming into prominence, there is little danger of its falling into disuse for many a long year to come. Of the two sources of power, gas and oil, the former is perhaps the more formidable rival with which steam has to compete. Where the bulk of the output from a colliery is converted into coke in coke-ovens, there remains in the gas given off an abundant source of power which may very economically be utilised for the purpose of power generation and for other uses.

As an example of the extent to which in some cases this source of power can be applied, we would mention the gas-engine power station at the Anna Colliery of the Eschweiler Mining Company, near Aix-la-Chapelle, in France.[1] At this colliery there are in all 342 Koppers coke ovens, and the power station is designed for the production of 16,000 horse-power from the surplus gas. This is equivalent to nearly 50 horse-power per oven.

Apart altogether, however, from the utilisation of the gas from coke-ovens for the driving of suitable engines, it may be mentioned that considerable economy may be effected by using the heated gases from the coke-ovens to help in the generation of steam. This latter use, however, is much less productive of economy than that of using the gas for driving an engine direct.

When all is said and done, it must be admitted that the most prolific and satisfactory source of power up to the present available at collieries is steam pressure generated at the works.

The necessary fuel can there be had at its cheapest rate, and if the many excellent appliances for the purpose are taken advantage of, the most inferior classes of coal may be burnt, and the steam generated very economically indeed.

As to the best type of steam-engine to adopt, that is too extensive a subject to be adequately discussed here. Suffice it to say that the horizontal long-stroke compound condensing engine is the most generally adopted at collieries, while, for the generation of large powers, the high-speed vertical engine and the steam turbine are probably the most economical and efficient.

The following pages we devote to the description of the more important types of prime movers adopted in up-to-date colliery electrical installations.

The Corliss Engine

The main feature of this engine lies in the construction and working of the valve gear. There are two separate admission valves, and two separate exhaust valves. Motion is transmitted to these valves by means of levers fixed to a wrist plate, which in turn receives its motion from the eccentric rod. In order that the steam

[1] *Trans. Inst. M. E.*, vol. xxxiii. p. 415.

admission valves may be quickly closed, the valve levers are connected to springs contained in dashpots. Briefly, the action of the valves is as follows :—

The wrist plate receives an oscillating motion from the eccentric rod. The connection between the admission valve levers and the connecting rods are by means of spring catches. These catches slip and cause the lever to be disconnected, and thus the valve is closed by means of the dashpot springs. The slipping of the catch at the right period of the stroke is dependent upon the action of the governor. The exhaust valves are directly connected to the wrist plate, and receive the same turning movement every time.

The advantages claimed for this form of valve gear are as follows :—

1. The valves being placed near to the cylinder ends, the admission and exhaust passages are short, and the clearance volume and surface is much less than in the ordinary type of engine.

2. In the horizontal type of engine the condensed steam in the form of water is taken away by the exhaust valves, which are placed at the bottom end of the cylinder; so the draining is done by natural means. The steam admission valves are placed on top end of cylinder.

3. The points of admission, cut off, release, and compression may be adjusted independently of each other.

4. Unlike the ordinary slide valve, the supply of steam is cut off instantly by the quick turning movement of the steam valve on closing.

5. As the exhaust steam is kept separate from the live steam, a reduction in condensation results.

The average speed of these engines varies from 130 to 240 revolutions per minute.

An example of the performance of a pair of compound Corliss engines, horizontal type, is given below.[1]

Diameter of piston, high pressure	30 inches.
,, ,, low pressure	56 ,,
Diameter of piston rods	6 ,,
Stroke	5 feet.
Clearance of high-pressure cylinder	4 per cent.
,, low-pressure cylinder	5 ,,
Diameter of air pump	$25\frac{1}{2}$ inches.
Stroke of air pump	20 ,,
Diameter of air pump rod	$3\frac{1}{2}$,,
Diameter of main steam pipe	12 ,,
Flywheel diameter, grooved to receive 30 ropes	26 ,,
Volume of receiver between high-pressure exhaust valves and low-pressure admission valves	117·12 cubic feet.

[1] Ripper's *Steam.*

Boiler pressure	112 lbs.
Piston speed	606 ft. per minute.
Total indicated horse-power	882·2.
Dry steam per I.H.P. per hour . . .	14·42 lbs.
Dry coal per I.H.P. per hour	1·74 lbs.

Trip Gear Engine

Fig. 69 shows sectional drawings of cylinder and valves of a trip gear engine made by Messrs. Marshall, Gainsborough. The gear consists of equilibrium double-beat valves A and exhaust valves N, one for each end of the cylinder, with suitable operating mechanism driven from the lay shaft M, which is geared to the engine crank-shaft by mitre wheels. The steam admission valves are lifted alternately by levers B, which are depressed at their outer end by the bell crank levers C. Motion is given to the bell cranks by eccentrics E, which reciprocate the side links D, carrying the bell cranks on pivots. A stop is provided so that the bell crank, which is counterweighed by its inner arm, occupies the correct position for engaging with the lifting lever B. The amount of engagement is constant, and the period of engagement is determined by the governor, which is connected to the shaft J. This shaft carries the eccentrics H, which vary the position of the trip pads G. The travel of the eccentric E brings the inner arms F of the bell crank levers C into contact with the trip pads G, and the further movement compels disengagement between lifting levers B and bell cranks C. Immediately disengagement is complete the valves close smartly and quickly under the influence of helical springs and the air cushion in the spring boxes L. Air valves K regulate the actual closing speed, and prevent undue pounding and wear between the valves and seats. The operation of the exhaust valves is effected by eccentrics on the lay shaft. The lower end of the exhaust eccentric rod is connected to lever O pivoted at P. The lever Q pivoted at R is extended past valve spindles, and rests on circular bosses of lever O when the valve is seated. The valve spindle is extended below the lever attachment, and connected to a spring S, which ensures the connection between the upper side of lever Q and pad T, and preserves a perfectly regular and silent motion. The upper side of lever O is curved to accelerate the rate of valve opening and give a free exhaust. The indicator diagrams (Figs. 69A and 69B) shown were taken from a coupled compound non-condensing engine made by Marshall.

High-Speed Engines

By the use of high-speed engines the generator may be coupled direct. This is an advantage over the slow-speed engine,

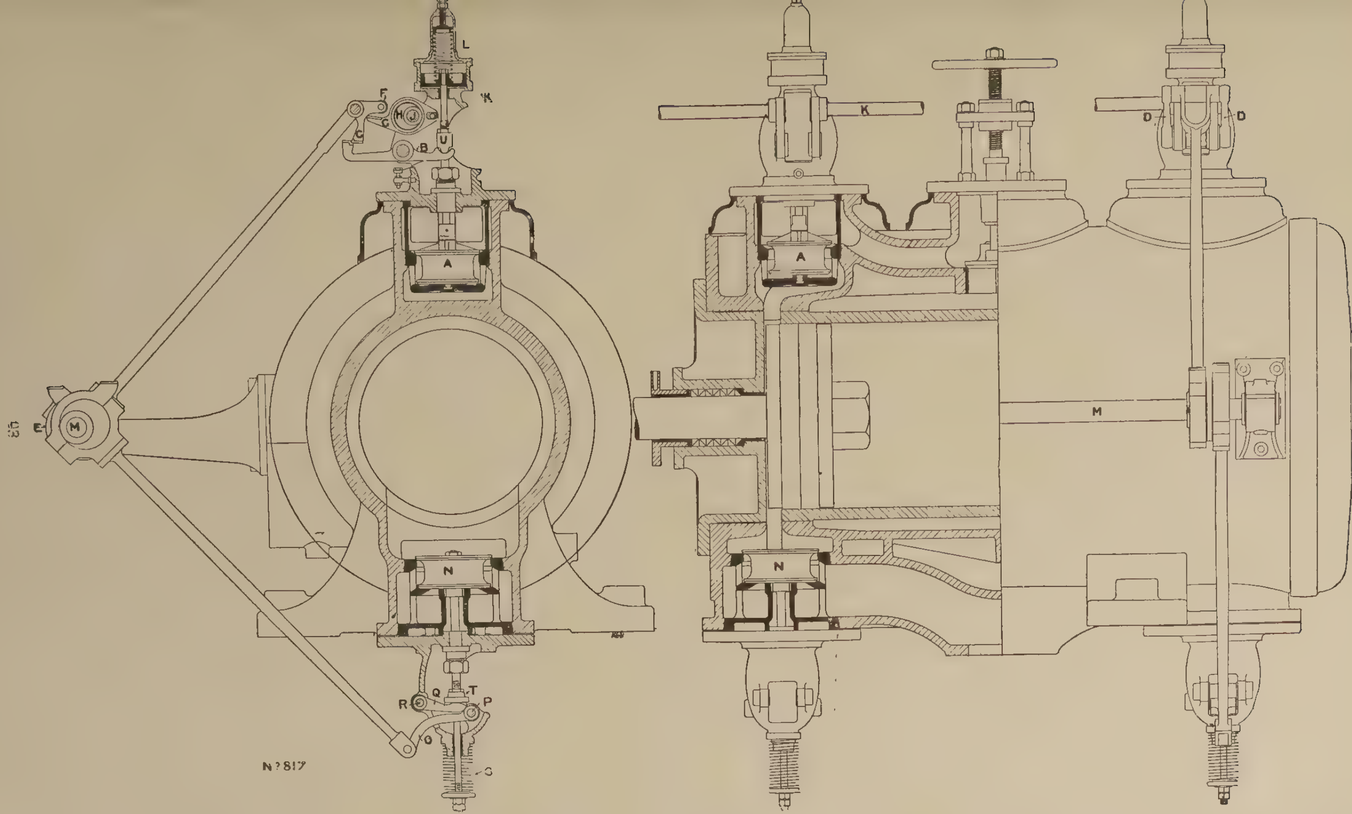
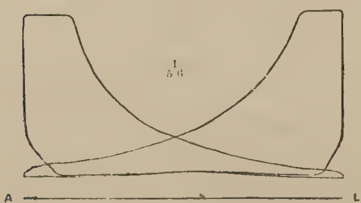


Fig. 69.—Marshall's trip gear engine.

where the power from the engine to the generator is transmitted by means of belting, ropes, or gearing. In addition to the compactness of the high-speed engine, it also requires less expensive foundations. These engines are made compound and triple expansion, and in sizes from 50 B.H.P. to 800 B.H.P., at 400 to 700 revolutions per minute. One of the best types of high-speed engines is the "Bellis," and it is extensively used for electric generation. The special feature of this engine is the arrangement of the slide valves, which require only one eccentric and rod. Fig. 70 shows sectional drawings of the Bellis engine. The lubricant is forced under pressure



HIGH PRESSURE DIAGRAM

Fig. 69a.

LOW PRESSURE DIAGRAM

Fig. 69b.

of 10 to 20 lbs. per sq. inch to the moving parts of the engine, and the film of oil between the working parts prevents them from making actual contact.

Steam-Engine Indicator

This instrument is used for showing the behaviour of the steam in the cylinder, to find the mean effective pressure exerted on the piston by the steam, to ascertain whether the valves are set correctly, and to determine the dryness of the steam, also the degree of expansion, extent of back pressure, loss by wire drawing, etc.

Description of the Indicator.—There are many different types in use at present, but the governing principle is the same in each. It consists of a piston working freely in a small steam cylinder; a spiral spring of definite strength is fixed to the piston at one end, and to the cover of the cylinder at the other end. This spring regulates the movement of the piston according to the steam pressure exerted upon it. Different springs are used for different pressures. When tested by the manufacturers they are stamped with a fraction, say, $\frac{1}{100}$; this means that the piston will rise a $\frac{1}{100}$th part of an inch for every pound of steam pressure per square inch on the piston. A brass wire pencil is carried by a link parallel motion from the top of the piston rod. This motion reproduces the vertical movement of the piston, but it is increased

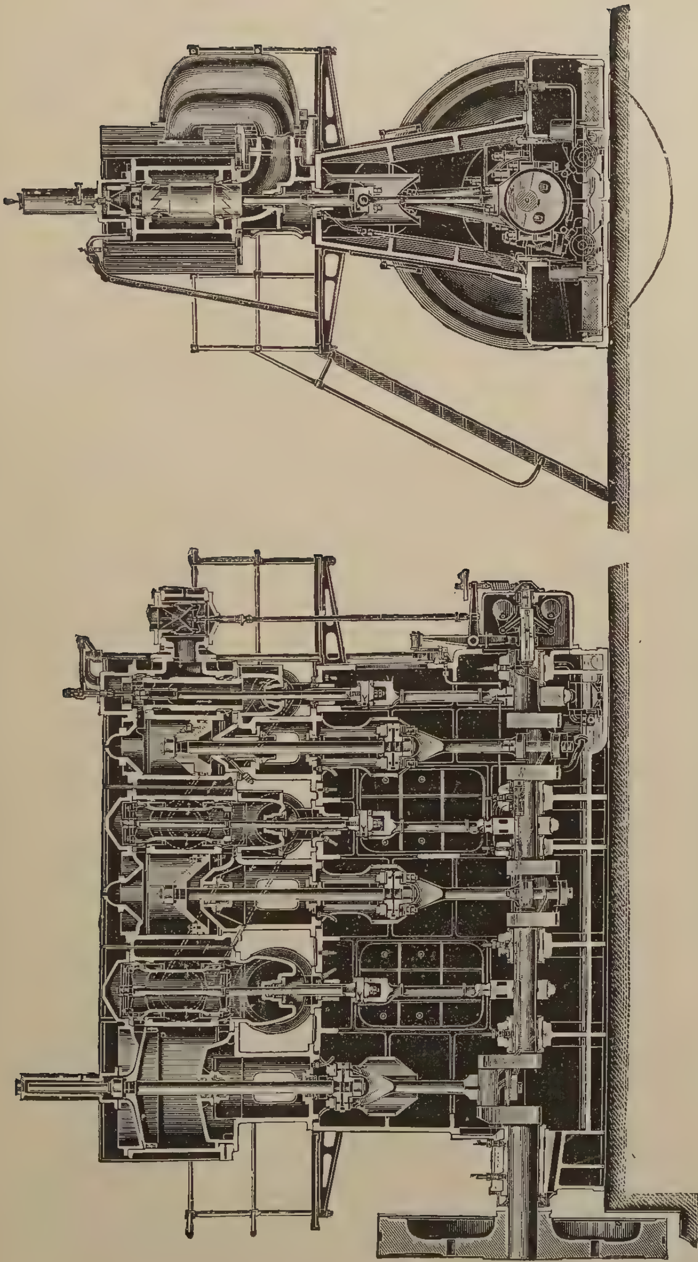


FIG. 70.—Sectional elevation of Bellis triple expansion engine.

in magnitude four, five, or six times on the indicator card, which is wound around a drum. This drum receives a backward and forward rotation on its axis by means of a cord attached to a reducing gear fixed on the crosshead. A spring inside this drum keeps the cord always in a state of tension. By the combined vertical and horizontal movement of the indicator card, the figures described by the brass pencil when it is placed against the card are that of two closed diagrams representing the effective work done by the steam on the piston during both strokes. See Figs. 69A and 69B.

The mean effective pressure may be found from these diagrams by dividing up into ordinates, or by the use of a planimeter. First get the average pressure during the stroke, then multiply by the scale of the spring used in the indicator.

Then where P = mean effective pressure in lbs. per square inch,
L = length of stroke in feet or distance travelled by the piston from one end of the cylinder to the other,
A = effective area of piston in square inches,
N = number of revolutions per minute for single acting engine,
,, = number of revolutions per minute for double acting engine,
,, = number of impulses per minute for gas engines,

$$\text{Then I.H.P.} = \frac{\text{P.L.A.N.}}{33{,}000} = \frac{\text{Units of work done per minute}}{33{,}000}.$$

The indicated horse-power (I.H.P.) represents the work done by the steam in the engine cylinder as found by using the indicator.

Example 1. Find the I.H.P. of a steam-engine. Diameter of cylinder, 15 inches; length of stroke, 18 inches; number of revolutions per minute, 100. Mean effective pressure on piston = 50 lbs. per square inch.

$$\text{Then I.H.P.} = \frac{\text{P.L.A.N.}}{33{,}000}$$

$$= \frac{(50 \times 15 \times 15 \times 0{\cdot}7854)\,\text{lbs.} \times (1{\cdot}6 \times 100 \times 2)\,\text{ft. per min.}}{33{,}000}$$

Brake horse-power represents the power available for doing useful work, after deducting the power absorbed by the engine in driving itself. The B.H.P. is measured by means of a brake dynamometer when the engine is not too large. Briefly, the apparatus consists of a rope or ropes coiled once round the circumference of the flywheel, and one end fastened to a spring balance fixed above flywheel. The other end of the rope hangs down, and is loaded with weights.

Where r = the radius of flywheel in feet,
N = number of revolutions per minute,
W = weight hung on bottom end of rope,
R = reading in pounds on spring balance at top end of rope,

$$\text{Then B.H.P.} = \frac{2\pi r N(W - R)}{33{,}000}$$

$$\pi = 3{\cdot}1416 \text{ or } \frac{22}{7} \text{ (approx.)}$$

and mechanical efficiency of engine $= \dfrac{\text{B.H.P.}}{\text{I.H.P.}}$

Mr. W. H. Weightman gives the following comparisons between single, compound, and triple-expansion engines.

—	Single Cylinder.	Compound Cylinders.		Triple-Expansion Cylinders.		
Diameter of cylinders in inches . . .	60	33	61	28	46	61
Area ratios	...	1	3·416	1	270	4·740
Expansions . . .	20	5	4	2·744	2·714	2·714
Initial steam pressures —absolute pounds .	165	165	33	105	60·8	22·4
Mean effective pressures —pounds . . .	32·96	86·11	19·68	121·44	44·75	16·49
Steam temperatures into cylinders . . .	366°	366°	259°·9	366°	293°·5	234°·1
Steam temperatures out of cylinders . .	184°·2	259°·9	184°·2	293°·5	234°·1	184°·2
Difference in temperatures	181°·8	106°·1	175°·7	72°·5	59°·4	49°·9
Horse power developed.	800	399	403	269	268	264
Speed of piston . .	322	290	290	238	238	238
Total initial pressures on pistons—pounds .	455·218	112·900	84·752	64·162	63·817	53·773

Power of Engine for Direct-coupled Dynamo (*Dawson*).—To find the approximate power of engine to drive dynamo of given kilowatt capacity, add one third and then 10 per cent. Example: dynamo, 150 kilowatts.

I.H.P. of direct connecting steam engine

$$= 150 + \frac{150}{3} + \frac{10}{100}\left(150 + \frac{150}{3}\right) = 200 + 20 = 220 \text{ I.H.P.}$$

Steam Consumption per Horse-power (*Dawson*).—The average total water consumption in existing steam-engines may be taken as

40 lbs. per indicated horse-power in non-condensing engines, 30 lbs. in condensing engines, and 22 lbs. in compound engines. In the absence of specific information it is not safe in practice to allow for a less consumption than the foregoing, although the following results are frequently attained with first-class designs :—

Non-condensing engines,	25 lbs.	per indicated	horse-power	per hour.
Condensing engines,	18	,,	,,	,,
Compound engines,	16	,,	,,	,,
Triple-expansion engines,	$13\frac{1}{2}$	,,	,,	,,

Better results even than these have been obtained.

Coal Consumption per Horse-power (Dawson).—A good result with a non-condensing engine is 3 lbs. of coal per indicated horse-power per hour, and with a condensing engine 2 lbs. First-class compound engines give considerably under 2 lbs., ranging from 1·75 to 1·5 lb., while triple-expansion engines range from 1·5 lb. to 1·25 lb. Compound non-condensing engines of only 20 indicated horse-power have, however, given as low as 1·8 lb. per indicated horse-power per hour.

Transmission of Power by Belting, Ropes, etc.

The transmitter of power between the engine and generator, if not coupled direct, may be a belt of leather, or hemp and cotton ropes. In the event of a breakdown with the belt drive, the whole plant must be shut down, but, where driving ropes are used, one rope breaking does not affect the driving power very much.

There are some points to be observed in the transmission of power, and these are :—

For Belting.—A much better effect is given by having the belt lying horizontally and a fair length of drive, than vertical short belts. A long belt working horizontally increases the grip by its own weight. If the distance between the pulleys be too great, the weight of the belting will produce a heavy sag, and this causes pressure to be exerted on the bearings, thus causing friction. An unsteady motion is also the outcome of having the belt too long. When two pulleys of diameters greatly differing from one another require to be connected, care should be taken to see that they are placed a reasonable distance apart, else the angle of contact on the smaller pulley will be so small as to render the belt liable to slip. The hair side of the belt should be run against the pulley, as greater friction is obtained. When slipping occurs, cut out 1 inch for every 10 feet, or increase area of contact with pulleys by using wider belt. When a belt chases or flaps, use heavier belting.

For Ropes.—Circumference of pulley should not be less than

thirty times the circumference of rope. The distance between the two pulleys should be from 30 to 60 feet. The ropes must not rest on the bottom of the groove, which is generally V-shaped. Working tension of the rope, from 110 to 120 lbs. per square inch of its section.

The length of a splice or join should be about fifteen times the circumference of the rope. The velocity of the rope is from 3000 to 6000 feet per minute. Ropes, $5\frac{1}{4}$ to $6\frac{1}{2}$ inches circumference, or $4\frac{1}{4}$ inches for small powers. According to Durie, the formula for hemp rope gearing is as follows:—

Where V = velocity of rope in feet per minute,
N = number of ropes,
C = circumference of rope in inches,
P = indicated horse-power.

$$P = \frac{C^2V(N - I)}{4000}$$

$$C = \frac{\sqrt{4000\ P}}{V(N - I)}$$

This formula is adopted upon the supposition that the number of ropes is one in excess of the actual number required, so as to provide for changing and repairs. In some cases, ropes have run for over ten years, but the average life of a rope is from three to six years.

Steam Turbines

Steam turbines are now recognised to be a commercial and mechanical success. In the larger sizes they are said to compare favourably with the best makes of reciprocating engine, having the advantage of applying a perfectly uniform turning movement to the driving shaft or spindle. The absence of vibration, small floor space required, small quantity of oil used, and the high vacuum attainable, give the steam turbine an advantage over the reciprocating engine, but the makers of reciprocating engines have during the past few years so perfected their engines that it is an undecided point whether the steam turbine is more economical in steam consumpt than a first-class compound condensing engine with Corliss gear.

The principle of the steam turbine is simple; Hero of Alexandria demonstrated this principle more than two thousand years ago. He used a boiler, two pipes from which led by means of right-angle bends into a hollow globe, the globe being free to revolve. Two L-shaped pipes or nozzles project from the sides diametrically opposite. On the application of heat to the boiler, steam enters the globe through the uprights and pivots, and escaping by the two L-shaped pipes causes the globe to revolve. The steam turbine is a rotary engine, no

reciprocating parts are used, and the speed is practically unlimited. The four principal types of steam turbines are: Parsons, De Laval, Curtis, and Rateau.

Parsons' Steam Turbine.—One of the most successful forms of steam turbines is that of Messrs. C. A. Parsons & Co., Newcastle. It consists of a cylindrical casing with projecting blades fixed to the inside of the casing. A concentric shaft having projecting blades revolves within the casing. The rings of blades in the casing nearly touch the shaft, and the rings of blades on the shaft nearly touch the casing, and lie between those on the casing. Fig. 71 shows the form of blades used.

The steam, on entering, passes through the turbine in an axial direction, and is exhausted at the exhaust chamber to the atmosphere

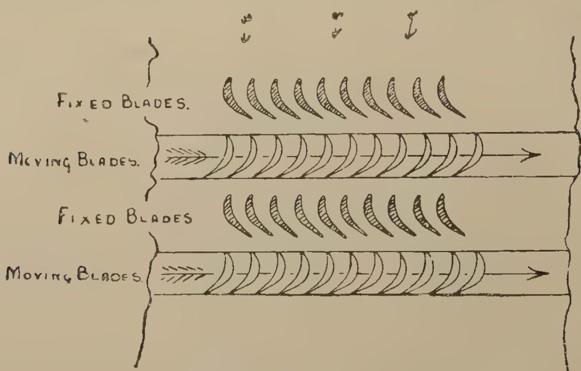


FIG. 71.—Blades in Parsons' turbine.

or condenser. After passing through a ring of fixed guide blades, the steam is projected in a rotational direction upon the succeeding ring of moving blades, and the reaction thus caused increases the rotational force or energy. This operation goes on through the successive rings of fixed and moving blades. The energy required to give the steam its high rotational velocity at each set of rings is obtained by the drop in pressure of the steam causing it to expand in small increments. Each set of rings has greater area in its passages than the preceding set; this is obtained by increasing the diameter of the rings. At the left end of the spindle are grooved pistons, or "dummies," which are made to fit into corresponding grooves in the cylinder. The object of these pistons or "dummies" is to prevent "end thrust," by setting up equal and opposite axial forces. These pistons also act as a practically steam-tight joint, since the clearance between the grooves may be adjusted longitudinally by a thrust block.

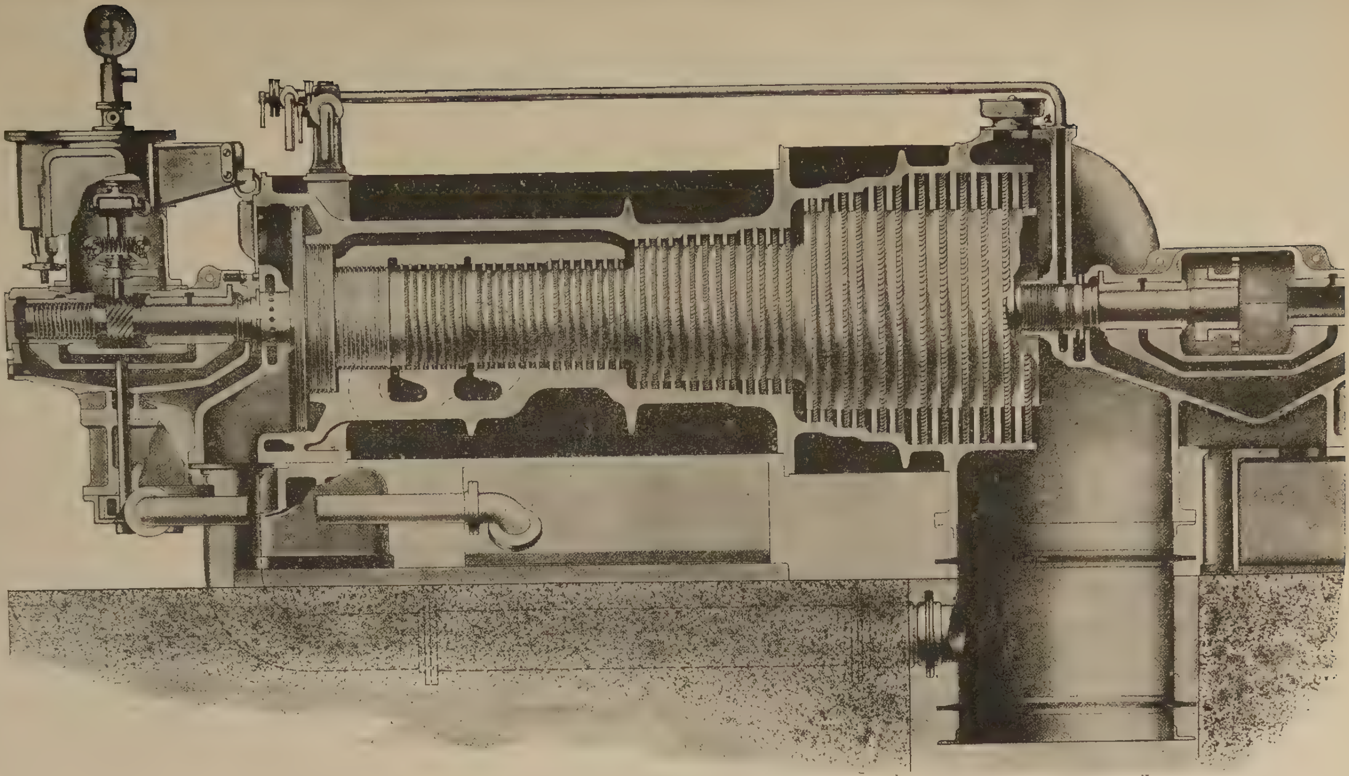


FIG. 72.—Parsons' steam turbine.

The bearings are of the tubular oil cushioning type. Oil is pumped into the bearing under a pressure of from 3 to 5 lbs. per square inch. The oil pump is driven by worm gearing from the turbine shaft. The governing of the turbine is accomplished as follows:—

The admission of the steam is by a series of gusts, or "blows," caused by the periodic opening and shutting of a double-beat valve.

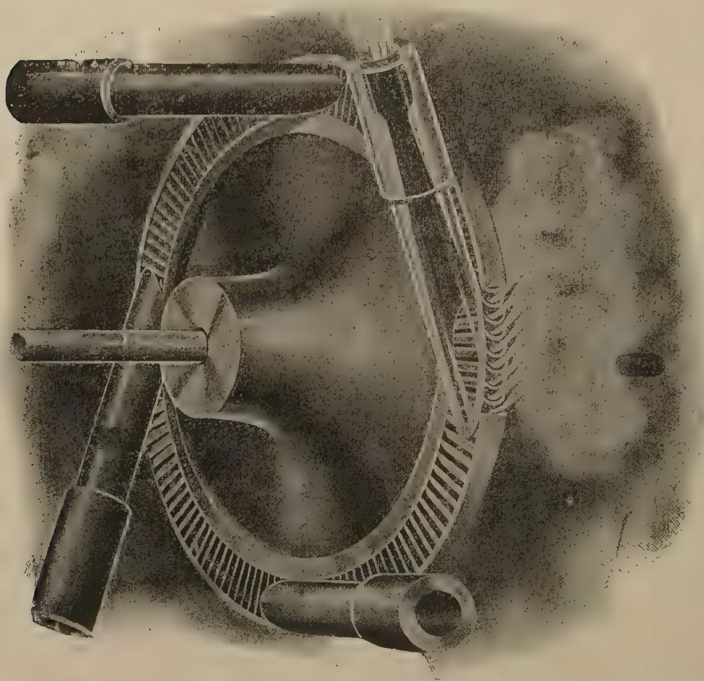


FIG. 73.—De Laval steam turbine, showing wheel and nozzles.

A governor operates this valve by means of a steam relay. The governor receives its motion from the turbine shaft. The lever to the steam relay is moved up and down by means of an eccentric, which also receives its motion from the turbine shaft. This up and down motion regulates the periods of admission of steam to the turbine. The speed of the turbine varies from 700 to 6000 revolutions per minute, depending upon the horse-power of the machine. Flexible couplings are generally used when coupling direct to generators.

When engines are running non-condensing, an exhaust steam turbine may be installed with advantage.

Fig. 72 shows a sectional elevation of Parsons' steam turbine.

De Laval Steam Turbine.—This type of turbine was introduced by Dr. De Laval about 1889. Little or no deviation has taken place from the original design. It has been used successfully for powers up to 500 H.P. The steam is blown from stationary nozzles with a velocity of from 3000 to 4000 feet per second against the vanes or blades of a revolving single turbine wheel. The steam passing through the vanes delivers up most of its energy to the wheel (see Fig. 73), and then flows at a much reduced velocity into an ejector condenser. As the successful working of this turbine depends upon the kinetic energy of the steam, it will be seen how important it is to

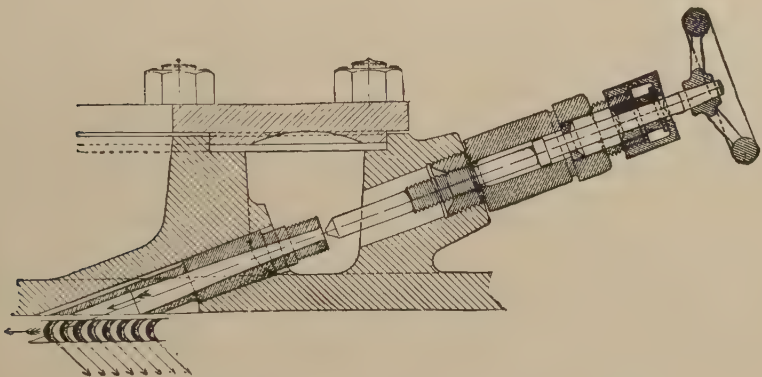


FIG. 74.—Shutting-off valve and nozzle for De Laval steam turbine.

have the steam enter the vanes at as high a speed as possible. Conical nozzles are used in order to expand the steam before entering the wheel. The expansion of steam in a nozzle from 280 lbs. pressure above atmosphere, down to a vacuum of 28 inches, enables the steam to leave the nozzle with a velocity equal to 4229 feet per second. The regulation of the steam supply is made by completely shutting off one or more of the nozzles (Fig. 74), leaving the others wide open, instead of throttling each nozzle independently. The nozzles are fitted close to the vanes of the wheel, the clearance space being about $\frac{1}{16}$th of an inch, and at an angle of 20 degrees with the plane of the wheel. The wheel itself is composed of a solid disc, the vanes being dovetailed in on the circumference. The wheel is keyed upon the turbine spindle, and supported at each end by bearings. It has been found impossible to perfectly balance a wheel revolving at so high a speed. This difficulty of vibration has been overcome by the use of a flexible spindle

and self-aligning bearing; by this means the wheel can revolve about its own centre of weight. The diameter of this flexible shaft is very small—in the case of a 300 H.P. turbine being only $1\frac{5}{16}$ inch diameter. The excessively high speed of the turbine wheel is geared down to one suitable for dynamo driving. A pinion is mounted on the outer end of the spindle, and gears into a machine-cut double helical wheel, which reduces the speed ratio from 10 to 1, thus the driving shaft or pulley runs at one-tenth of the speed of the turbine spindle. A De Laval turbine of 5 H.P. has a wheel diameter of 4 inches, with a peripheral speed of 515 feet per second; revolutions of wheel, about 30,000 per minute. Before the steam enters the steam space on its way to the nozzles it is regulated by the action of a centrifugal governor upon a double-seated valve, which is connected by link motion to the governor. The governor is fixed in a horizontal position on the end of the gearing shaft. An oil tank is fixed above the turbine, and supplies oil to all the bearings. The oil used should be light mineral oil—heavy oils carbonise and oxidise with the heat. After the oil has done its work it is collected in reservoirs below, and when filtered may be used again. With a decrease of steam pressure in the casing of the turbine, due to reduced loss by what is termed "fluid friction" between the revolving turbine wheel and the low-pressure steam surrounding the wheel, the efficiency of the turbine increases. It will, therefore, be seen that, for efficient working, condensers must be used. The "ejector" system of condensation has much to recommend it, being cheap and simple. No air pump is required. A suitable head of water, say, 20 or 30 feet above the level of the turbine, descending passes through a jet arrangement and is broken up when it meets the exhaust steam, thereby condensing it. The water of condensation flows into a tank in which the tail pipe is below the surface of the water, thus creating a vacuum, and therefore increasing the efficiency of the turbine. Other forms of condensers, such as jet and surface types, may be used. Fig. 75 shows a De Laval steam turbine installation.

The Curtis Steam Turbine.—This turbine consists of a number of wheels through which the steam passes, each wheel constituting a "stage" or "expansion." The steam is admitted with a high velocity through nozzles, as in the De Laval type. By using more than one turbine wheel a high thermal efficiency, due to the exhaust steam being at a low velocity, is obtained. Wheels to the extent of two, three, four, and six in number have been used. The wheels are separated from one another by a stationary plate or diaphragm, each diaphragm containing nozzles. Stationary guide blades in the form of a ring are fixed to the outside cylinder. These blades guide the steam into the revolving wheels. Briefly, the process consists first of the steam expanding through the nozzles, and, meeting the first wheel, delivers up a portion of its velocity by impulse. This

operation is repeated through two or more "stages" or "expansions" by meeting with other wheels, until the steam, after leaving the last wheel, has lost all its available energy. The circumferential velocity depends upon the degree of expansion and the number of "stages" or "expansions" through which the steam passes. Many "stages" means lower circumferential speed. In design this turbine differs from the Parsons or De Laval type, the rotating parts lying in a horizontal place, the shaft being vertical. The Curtis turbine is fitted with an electric generator to the top part of the turbine, and a condenser occupying a lower tier. The complete machine, dynamo, turbine, and condenser, standing on one base, economises floor space, which may be an item of importance in a small engine room. The rotational speed of a 2000 K.W. Curtis turbine is

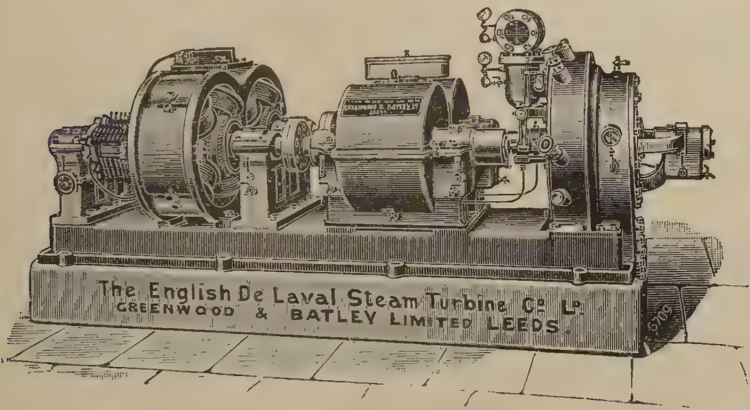


FIG. 75.—De Laval steam turbine installation.

1000 revolutions per minute. Governing by admission valve is effected by closing successive nozzles, which admit steam to the first wheel or "stage." The whole weight of the moving parts is carried by a footstep bearing consisting of two semicircular pads, one rotating with the shaft, the other fixed to the casing. Water at a pressure of 400 lbs. per square inch is forced by a pump through a hole in the stationary bearing, and forms a thin film between the two pads; the water also lubricates the guide bearing immediately above the pads.

The Rateau Steam Turbine.—This turbine is a horizontal multicellular machine of the impulse type, each turbine consisting of a number of sections, each section comprising one stationary and one moving wheel. The discs of the moving wheels are made of steel, and nickel-steel fixed vanes are fitted round the periphery of

the discs. Each moving wheel revolves between circular diaphragms with distributing vanes. Between two adjoining diaphragms there is a space in which the moving wheel revolves. Starting at the first diaphragm through which the steam passes, the distributing vanes are placed only on a part of the circumference, so that the steam is partially injected to begin with, and the velocity is taken fuller advantage of. The succeeding distributers are set with an angular advance on the preceding ones (see Fig. 76). The angle of advance is so arranged that the steam leaving one moving wheel enters into the next distributer and always finds a passage, so that there is little shock or loss of kinetic energy. The last distributer in the turbine has vanes set upon the whole circumference of the diaphragm.

FIG. 76.—Distributing vanes, Rateau steam turbine.

GAS-ENGINES

When a new installation is being planned, the question naturally arises as to whether gas- or steam-engines are to be used as prime movers. The decision arrived at depends upon the enterprise of the firm, and the existing conditions at the pit or mine. If the coal mined is of the coking kind, then there arises little doubt as to which is the more economical source of power. The oven gas may be utilised in gas-engines. Of course, the power may be obtained by means of coke-oven gas-fired steam boilers, but this is a roundabout way to secure that which may be obtained by using the gas direct in the engine. Not a few engineers are prejudiced against large gas-engines, but this prejudice is being rapidly broken down. At first it was thought that gas would be unsuccessful in driving alternators, but later practice has shown that this is wrong, and alternating current stations driven by gas-engines work successfully, and the question of periodicity and running in step with alternating

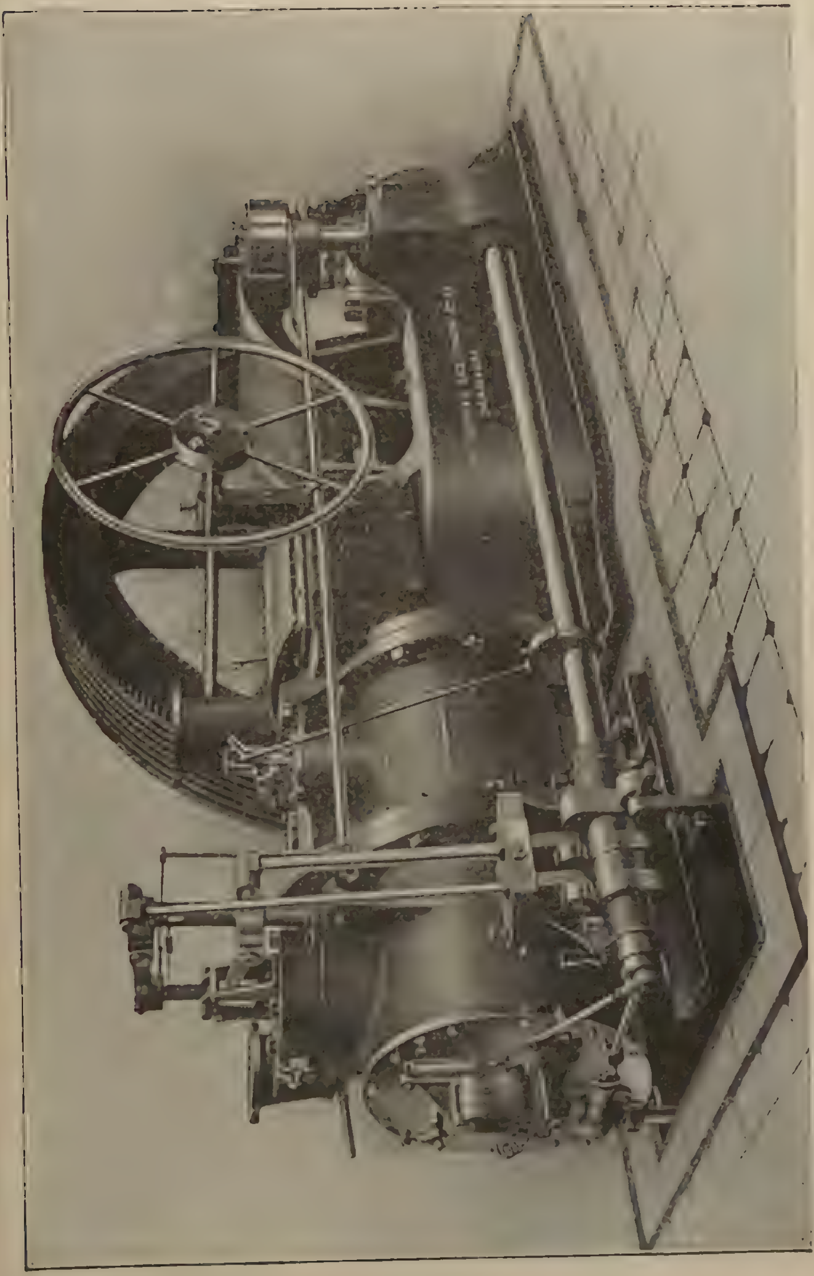


FIG. 77.—150 H.P. Premier gas-engine.

current machines in parallel is now solved. Fig. 77 shows a 150 H.P. Premier gas-engine. It is called "positive scavenger type" because the products of combustion, which are usually allowed to remain in the clearance space behind the piston in an ordinary gas-engine, are swept out by a charge of air forced through the clearance space in a positive manner. It will thus be seen that the incoming charge of gas and air is not contaminated and heated by burnt gases, but mixes with pure and cool air, which supports combustion. It is therefore possible to use weak and poor gas, such as is given off in large quantities from blast furnaces. It is also specially adapted for the use of rich gases, such as coke-oven gas, oil gas, etc. In large engines the ignition is usually electrical, low tension with external current, or high tension and magneto type. The starting arrangement consists of a pump which forces a charge of air and gas into the cylinder, ignition taking place by means of the electric spark. Another method has been adopted, which admits compressed air into the cylinder at the right period of the cycle. A high-speed spring-loaded governor operates the gas valve, and varies the quantity of gas admitted.

The Diesel Oil-Engine

This engine works on the Otto cycle or "four-stroke" principle. The first stroke, which is in an outward direction, draws air into the cylinder. The return or upward stroke compresses this air to about 500 lbs. into a small clearance space at the cylinder top. By compressing the air the temperature is raised to about 1000° F., which is a sufficient heat to ignite the spray of oil fuel injected into it by a jet of air at about 750 to 800 lbs. per square inch. The oil is stored and supplied by a steel reservoir, which is automatically kept charged with air by a compression pump. The spray of oil fuel atomises the air, and burns steadily as long as it is injected into the cylinder, so that the oil is burned during every working stroke of the engine. A highly sensitive governor controls the pump which regulates the supply of oil fuel. The products of combustion are exhausted through the exhaust valve, which opens at the end of the working stroke and remains open during the next "in" stroke. The Diesel engine differs from all internal combustion engines in the following respects:—

1. Air only is compressed. No explosive mixture is drawn into the cylinder. The compression of the air raises a temperature of heat sufficient to ignite and support the combustion of the hydro-carbon oil fuel.

2. The air drawn in is always constant in volume, and sufficient to burn the maximum supply of oil required at full load.

3. The admission of air takes place at or near the dead centre,

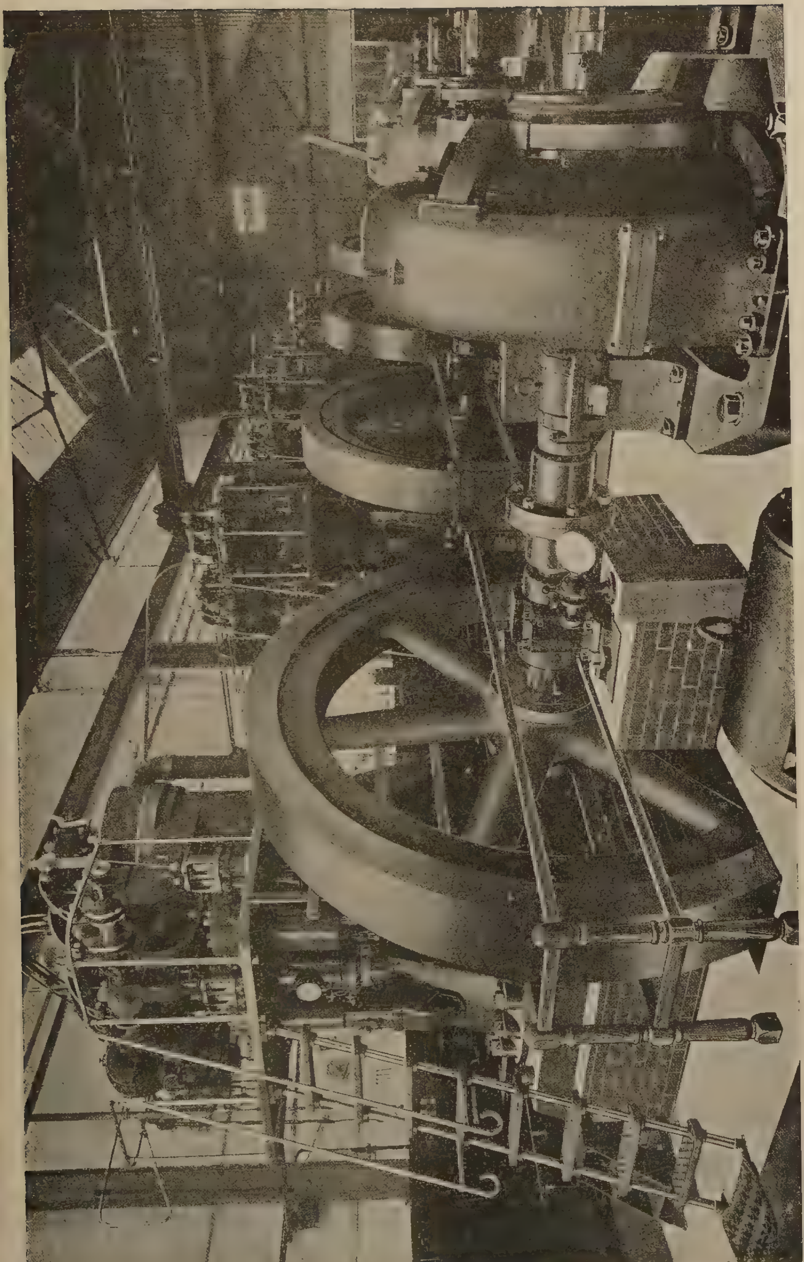


FIG. 78.—Diesel oil-engines, driving generators.

and automatically ignites and burns during a greater or less proportion of the following working stroke.

4. The heat is not suddenly generated by explosion, so that high temperature and shocks are avoided.

The difference between an "explosion" engine and the Diesel engine is that when hydro-carbon and air combined is ignited the entire mass is suddenly raised in pressure and temperature, so that the heat generated is therefore all added to the mass immediately before it has time to expand. This we call an explosion. On the other hand, as we have already explained, air is drawn into the cylinder of the Diesel engine, compressed, its temperature being raised in the process of compression, oil fuel is then injected gradually in a spray during a greater or less part of the working stroke, meanwhile the compressed air is expanding at constant pressure. The combustion gradually obtained is the chief point in the Diesel cycle, and herein is the marked difference between the Diesel and other internal combustion engines. Fig. 78 shows a central generating station in which Diesel oil-engines are employed.

Water-Power—Prime Movers

The power of falling water is recognised to be the cheapest and most efficient source of power yet known. The first cost and upkeep of the turbine is small when compared with other prime movers. A water turbine is the most efficient engine, giving back from 70 to 80 per cent. in useful work of the energy supplied. Water turbines are constructed for any head of water. For falls above 100 feet Pelton wheels are found to be very suitable. If there is any water-power available about a mine or colliery the question arises—How can it best be utilised? This depends largely upon the head of water, or distance through which it falls, and the quantity available.

The Double Vortex Turbine.—The water enters at the top of the casing, and is guided by four blades to the outside circumference of the turbine wheel, and causes it to rotate. The velocity is dependent upon the height of the fall. After the water expends its energy in giving motion to the wheel it is discharged through two exhaust pipes fitted to the centre of the casing. The angle of the guide blades may be altered by turning the hand wheel shown in the right of the illustration, Fig. 79. The opening to the wheel may be diminished or increased, depending upon the quantity of water at hand.

The Single Vortex Turbine.—This turbine is practically similar in construction to the double vortex turbine, with the exception that the shaft is vertical, and the water is discharged from one side

of the casing only. This turbine works with a fall of 4·5 feet, and uses 8,500 cubic feet of water per minute.

Fig. 80 shows how water-power may be employed for operating electrical machinery.

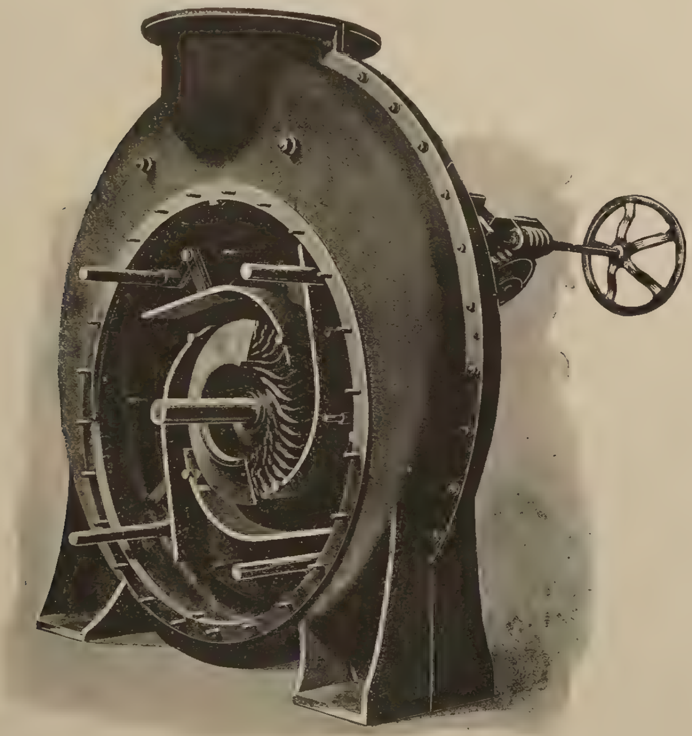


Fig. 79.—Double vortex water turbine.

The Pelton Wheel.—The principle of the Pelton wheel may be gathered from Fig. 81. The wheel is contained in the casing, and supported by means of a shaft in gun-metal bearings fixed to each side of the casing. The nozzle, which is shown in the drawing, fits into the oval hole in the casing. The water supply is directed through the nozzle, and the jet impinges centrally on the buckets of the wheel, divides and circles round, giving up its momentum to the wheel, and is then discharged at the bottom of the casing. The shape of the bucket is such that the maximum amount of momentum is

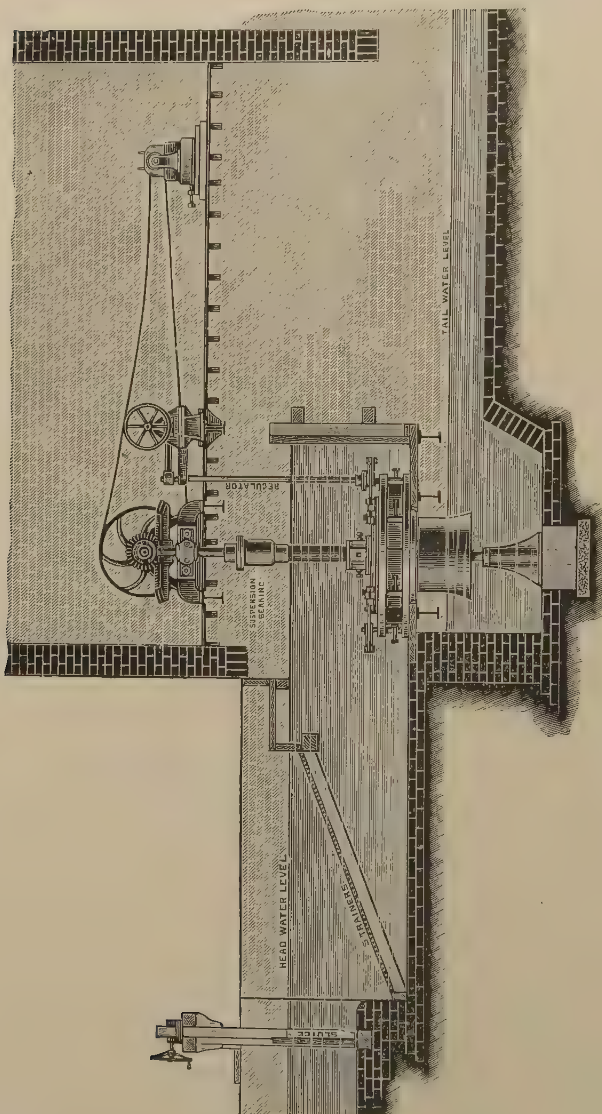
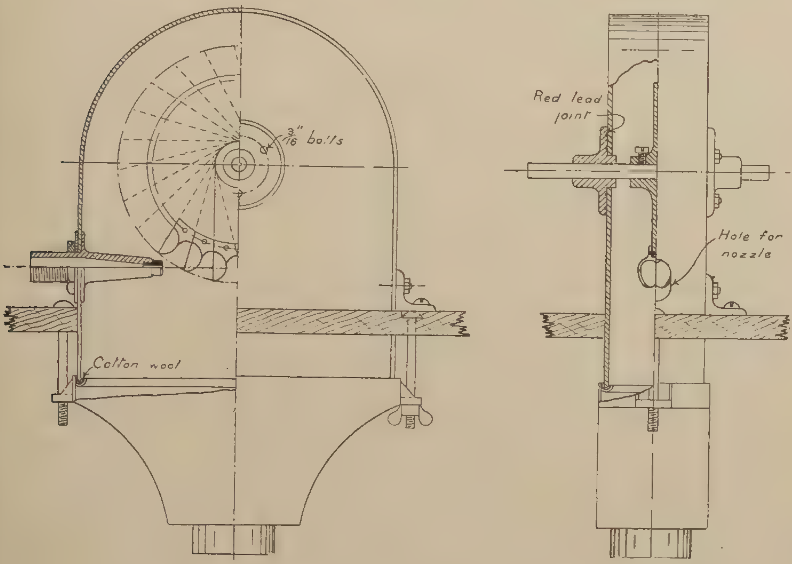


Fig. 80.—Water turbine electrical installation.

abstracted from the water. The efficiency of this wheel is very high, and but for the imperfect action of the water reaching the buckets, due to their different inclinations caused by the revolving wheel, and



Half Sectional Elevation. Half Sectional End View.

FIG. 81.—Pelton wheel.

one bucket interfering with the supply of the other, the efficiency would be over 98 per cent. The Pelton wheel shown in the drawing was designed by one of the authors for charging electric accumulators.

CHAPTER V

LIGHTING BY ELECTRICITY

Advantages and disadvantages—Arc lamps (open and enclosed)—The mechanism of an arc lamp—Alternating current arc lamps—Choking coils—Economy coils—The Excello flame arc lamp—Incandescent lamps—The filament—Efficiency and illuminating power—The Nernst lamp—The Osmium lamp—The Tantalum lamp.

Electric Lighting at Collieries

Numerous and important advantages may be claimed for electric lighting as an invaluable aid to the safer and more efficient working of colliery operations, both above and below ground.

In underground operations, previous to the introduction of electric lighting, the invariable source of illumination in positions where extra light—beyond the faint gleams provided by the private lamps of the miners—was desirable, was large hanging or fixed lamps burning paraffin; and such being unsafe in mines, even the least fiery, were substituted by extra large safety lamps suspended in similar fashion, in mines where General Rule 8 of the Coal Mines Regulation Act applied.

These somewhat antiquated modes of underground illumination have in later years been to a great extent supplanted by the better and modern method of lighting by electricity.

On the surface, too, in shunting operations, in engine-rooms, and in the various operations connected with the banking, screening, sizing, cleaning, and loading of the coal, electric lighting has become paramount, and its use practically universal.

In electric lighting there are two distinct forms of lamps, namely, the arc lamp and the incandescent glow lamp, but the latter form all but monopolises the field for colliery work, although for lighting railways, sidings, and pit heads, the arc lamp may be used with considerable advantage.

The glow lamp is much less efficient than the arc lamp, but it possesses the very important advantages of being safer in fiery situations underground, and of greater adaptability for distribution. By the latter advantage, we mean that a considerable number of glow lamps may be placed at short intervals apart, and fixed in any desir-

able situation at less expense and with more satisfactory results than can be had with even a very few lamps of the arc type.

The following is a brief enumeration of the advantages and disadvantages of electric lighting for colliery work :—

1. Advantages—

(1) Greater lighting power.

(2) Consequent immunity from the many dangers which poor lighting gives rise to.

(3) Little or no trouble with lamps.

(4) Cheaper in cost of maintenance of light than oil lamps.

(5) Adaptability for fixing in almost any situation.

(6) Suitability for use in sinking shafts, where its use is of great service.

(7) Perfect safety in fiery mines, when open paraffin lamps would be a source of great danger, and where the poor light of hanging safety lamps is of itself a great argument in favour of the adoption of electric lighting.

(8) Entire absence of any obnoxious smell or vitiating fumes.

(9) Absolute cleanliness.

2. Disadvantages. The disadvantages of electric lighting are practically confined to the following :—

(1) Necessity for generating plant. This is, of course, of little consequence where the electric current generated is used for pumping, hauling, or coal-cutting, as well as for lighting.

(2) Laying and fixing of lighting cables.

(3) Dynamo has often to be run for lights alone, when pumps, etc., are off, and this is, of course, expensive. This can be obviated by having a small plant for lights alone.

(4) Cost of lamp renewals.

In the subsequent pages will be found a description of the most important types of both the arc and the incandescent glow lamps.

Arc Lamps

Arc lamps are made "open" and "closed," and are very suitable for outside lighting, such as pit heads, sidings, etc.

The range of light varies from 500 to 6000 candle-power.

The light emitted by the arc lamp is practically the same as sunlight. Suppose two carbon rods are made to touch one another (each rod being connected to an electrical circuit through which a current is flowing), then, on the rods being drawn slightly apart, a luminous "arc" is formed. This "arc" forms the conducting medium from one carbon to the other. The temperature of the arc is stated to be 3500° C. The positive carbon, which is usually uppermost in the lamp, is made twice the size of the negative. It is made thus because of the difference in the consumpt of the

carbons, the positive carbon "wasting" twice as quickly as the negative. The end of the positive carbon assumes the form of a "crater" or bowl, while the negative remains pointed. This is why the positive carbon is placed on top, so that the light emitted is cast downwards from the "crater" or bowl. Positive carbons with soft cones are used so that more perfect "craters" are formed.

Open Arc Lamps.—Open arc lamps consume 10 amperes per 1000 candle-power. An arc taking 10 amperes at 45 volts requires 450 watts-power. Suppose we had a circuit with a pressure of 220 volts. Instead of wasting the current by heating up resistances, the lamps can be connected in series across the circuit, thus five arcs consume 10 amperes × 220 volts = 2200 watts, or 440 watts per lamp. Four arcs on this circuit would consume 550 watts per lamp. Two arcs in series on a 110-volt circuit, and four arcs in series on a 220-volt circuit, with steadying or "series" resistances, is common in practice. When a large number of lamps are connected in series, then the steadying or "series" resistances may be dispensed with, as the lamps act as a resistance to one another. Where no steadying or "series" resistance is inserted, automatic cut-outs are used. When it is required to switch off an arc of a series, a counterbalancing resistance must be switched in. This is done automatically by a switch in the lamp itself. If failure occurs on the part of one lamp in the series, this automatic switch comes into play, and the other lamps are not affected.

The Mechanism of the Arc Lamp consists of two coils, the "series" and the "shunt," both acting in combination through mechanism which has the effect of regulating the distance between the carbons, so that when the current is flowing an arc will be "struck," and the proper distance between the carbons maintained.

Alternating Current Arc Lamps.—A.C. lamps should not be used on D.C. circuits, and *vice versâ*. These lamps have a lower efficiency than the former, due to the reversal or alternating of the current. The positive and negative carbons, changing their polarity, cast half of the light upwards and the other half downwards. The temperature of the arc is not so high as in the continuous current lamp. Each of the carbons become "positive" time about, so that the heat is more distributed than in the case where the "positive" is stationary and assumes a "crater." The carbons used in A.C. lamps are equal in diameter, and both tend to assume a pointed shape. The E.M.F. required is about 35 volts, and the efficiency is about 1·12 watt per candle-power.

Choking Coils are used on alternating current circuits instead of steadying or series resistances. The choking coil is a very efficient apparatus. It is used to "choke" back high voltage without much loss. It is therefore possible to use a series of two, or only one lamp, on a 220-volt circuit without appreciable loss. By a small expendi-

ture of energy in the coil a high counterbalancing pressure "chokes" back the extra pressure.

Economy Coils are used where alternating current arc lamps are placed singly. These coils are a combination of transformer and choking coil.

Open arc lamps require to be trimmed periodically with fresh carbons, usually every 8 to 20 hours according to type of lamp used. The "Flame" carbon now extensively used emits a more pleasant light than the ordinary carbon, and possesses the additional advantage of penetration in foggy weather. These carbons are made with an admixture of calcium, the presence of which causes a yellowish flame around the arc.

Enclosed Arc Lamps.—The arc in this lamp is formed in an enclosure from which the air is more or less excluded. The carbons are enclosed in a small cylindrical globe inside the outer one. When the arc is "struck," the carbon, combining with the air in the inner globe, forms carbon monoxide, which fills the globe and prevents further admission of air, and being a non-supporter of combustion the carbons volatilise. This is the chief loss with the carbons. The carbons tend to assume a flat shape at the ends, instead of being pointed as in the open arc. The light emitted by this lamp is well diffused and steady when both outer and inner globes are opalescent. The arc being longer than the ordinary, a better distribution of light results, although the candle-power is sometimes 40 per cent. less. This better distribution of light is due to the inclination of the arc, which forms a cone of 75°, while in the open arc the cone is 45°. The enclosed arc lamp works with a voltage of from 75 to 90, and with the resistance usually fitted inside the lamp it may be connected right away on a 100-volt circuit. As the carbons last from 120 to 200 hours, less trimming is required than in the open type. A nominal C.P. lamp takes about 7 amperes, but lamps are constructed to take 2·5 to 5 amperes. For inside work enclosed arcs are safer, there being less risk from fire due to falling carbon sparks.

The Excello Flame Arc Lamp.—This lamp may be worked at 50 volts, and is very efficient, giving 10 candles per watt. They are made in sizes to emit as much as 3500 candle-power. The carbons which contain certain metallic salts are consumed quicker than the ordinary carbons, hence they are made longer, and have a metallic core running down the centre. The light emitted is not unlike sunlight, and owing to the absence of cast shadows the lamp is eminently suitable for lighting up open spaces.

Incandescent Lamps

The number of lamps required in an installation is determined by the illumination necessary. For offices, from 50 to 60 C.P. per 100

square feet of floor area is usually allowed; while for engine-rooms 20 to 30 C.P., and for underground illumination 15 to 20 C.P. Reflectors add to effective lighting. Dark or black walls absorb about 15 per cent. more light than white walls. It is more economical to use a large number of small candle-power lamps instead of a small number of large candle-power. Both arc and incandescent lamps may be run on a single circuit. For lighting underground, the incandescent lamps are often enclosed in a gas-tight outer glass globe.

The *filament* of an ordinary incandescent glow lamp is made from pure cotton wool dissolved in chloride of zinc. The wool is formed into a thread, and allowed to remain in alcohol for some hours. This gives a hardening effect, and removes the chloride of zinc. The next process consists in washing the thread in water to clean away the alcohol. It is then wound in the form of a loop on a carbon cylinder, and put into a crucible filled with carbon dust, then heated in a furnace to a temperature of 1000° F. The thread then becomes pure carbon, and is very brittle. The filament or thread is then enclosed in a vessel minus air, this vessel containing benzine vapour. When a current is passed through the filament, carbon from the benzine vapour settles or deposits upon it, making the thin places thick and the whole filament perfectly uniform in thickness throughout. This process is called "flashing." The necessary connections are then fitted to the filament, and the whole is placed in a globe or bulb, and the air is gradually withdrawn by means of air and mercury pumps. The bulb is then sealed and the finished lamp is tested to see if the vacuum is perfect, and also for the required efficiency and candle-power.

The absolute safety of the incandescent electric lamp in fiery situations is doubted by some eminent authorities. Certainly the production of light in an incandescent lamp is dependent upon the preservation of a vacuum in the interior of the bulb, and immediately this vacuum is destroyed through the bursting of the bulb the incandescence instantaneously disappears. But the problem arises as to whether the rush of the explosive atmosphere around the lamp filament may not take place before the temperature of the filament falls below the point of ignition of the gas. Whether this may or may not be the case has not yet been satisfactorily demonstrated, either theoretically or experimentally, and until this has been done there will still remain, in some minds at least, some little doubt as to the absolute safety of the electric incandescent lamp in fiery mines. Notwithstanding, the bulk of expert opinion is as yet in favour of pronouncing the incandescent lamp perfectly safe even in the presence of fire-damp.

The efficiency is generally expressed as the number of watts used per candle-power.

$$\text{Efficiency} = \text{candles per watt} = \frac{\text{C.P. of lamp}}{\text{watts absorbed by lamp}}.$$

The efficiency varies from 2·5 to 4·5 watts per candle. The life of these lamps varies from 800 to 1400 hours. Lamps are made to absorb 2·5 to 3 watts per candle; these are termed "high efficiency" lamps. Lamps taking 3·5 to 3·75 watts per candle are termed "standard medium," while lamps taking 4 to 4·5 watts per candle are termed "low efficiency long life" lamps. Circumstances decide the most economical kind of lamp to be used. Where power is cheap, then the last-named lamp may be the most economical, using more current but lasting much longer. Where power is expensive, it may pay to gain in power and lose in "life" by using the first-named.

Measuring the Efficiency of an Electric Lamp—"Photometer" Method

To measure the illuminating power of an electric light we use a "photometer." In its simplest form it consists of a "standard" candle, voltmeter, ammeter, white paper screen with vertical rod projecting a few inches in front of it, and the incandescent lamp to be tested. The lamp is placed at a suitable distance from the screen. The candle is adjusted backwards or forwards from the screen until the shadow caused by it is equal in darkness to the shadow caused by the lamp. The part of the screen not in shadow is illuminated by both lights, while the shadows are illuminated by only one light, and as the screen and rod are so adjusted that lines drawn through the centre of the rod and each of the lights make equal angles with the screen, so when the shadows are equal in darkness the quantities of light falling per square inch on the screen due to the candle and lamp are equal to each other, therefore

$$\frac{\text{The illuminating power of electric lamp}}{\text{The illuminating power of standard candle}} = \frac{E^2}{C^2}$$

The readings of the volt and ampere meter multiplied together give the number of watts supplied.

$$\text{Therefore the efficiency of the lamp} = \frac{E^2}{C^2 \times W}$$

The Nernst Lamp

This is an efficient type of lamp. It absorbs about 1·3 watt per candle. It may be run on 110 and 220-volt circuits, taking current to the extent of 0·25, 0·5 and 1 ampere. A substance called zirconia is mixed with different oxides, and made in the form of a thin rod; this "glower," as it is called, is placed in the centre of a

heating coil of platinum wire. A steadying or "series" resistance is put in series with the glower. A solenoid with a soft iron core is connected in series with the glower and steadying resistance. The function of the solenoid is to cut out the heating coil when the glower becomes incandescent. This generally takes about one minute after the switch is turned on. Unlike the ordinary incandescent lamp, the filament in the Nernst does not burn in vacuum. The light emitted is of a soft white colour, and pleasing to the eyes.

The Osmium Lamp

The filament in this lamp is made of osmium wire. A high candle-power is attainable, owing to the high temperature to which the osmium wire may be raised. The lamps work on 50 and 110-volt circuits, and absorb 1·66 watt per candle, giving an efficiency of 0·6 candle per watt. When the lamp comes into more extended use the price per candle will be greatly decreased. The life of this lamp is claimed to be between 2000 and 3000 hours.

The Tantalum Incandescent Lamp

The average life of this lamp is from 800 to 1000 hours, absorbing 1·5 watt per candle. The filament is made from the metal tantalum; owing to its low resistance the filament is made very long, over two feet, for a 100-volt lamp, giving 30 C.P. A special zigzag construction is adopted, which enables the long filament to be enclosed in an ordinary-sized vacuum globe. When compared with osmium, tantalum is found to be stronger, and capable of working at a higher voltage.

CHAPTER VI

INITIAL OUTLAY AND WORKING COST OF ELECTRICAL INSTALLATIONS

Steam boilers: Cornish, Lancashire, and Galloway tube—Water tube—Prime movers: Horizontal coupled engines—High-speed vertical—Compound condensing and triple-expansion—Steam turbines—Gas and oil engines—Water turbines—Generating plant: Continuous current dynamos and motors—Alternating current dynamos and motors—Transformers—Cables—Electric lighting—Cost of gas-driven plant to generate 1200 H.P.—Cost of steam turbine plant of 1200 H.P.—Actual costs of electrical plants of 120, 550, 900, and 1800 H.P.—Cost of working colliery electrical installations—Comparison of motor and steam driving—Costs of steam power and electrical power—Actual cost of producing electricity at a colliery under normal conditions—Results of steam turbine tests—Cable losses and motor efficiencies—Cost of working a gas-power plant of 1200 H.P.—Costs of working turbo-generating plant at Hulton Colliery.

The installation of electrical generating plant and the subsequent utilisation of the current generated in haulage, pumping, coal-cutting, and colliery work generally introduces the necessity for very considerable initial outlay, especially if the installation is an important one.

In this respect, electrical plant for colliery work compares somewhat unfavourably with the old-established system of the direct utilisation of the power generated in the steam boilers, with no other medium save the engine or engines necessary for the different classes of work in active operation.

Electrical generating plant may, from one point of view, be looked upon as an additional and, *prima facie*, altogether unnecessary item of expenditure, seeing that, in the steam generated in the boilers, we have a convenient source of power ready to hand.

But, although the conversion of the mechanical power of the modern steam-engine into electrical energy through the medium of an electric generator must ever mean a considerable increase in capital outlay, it may yet be safely assumed that the subsequent saving in cost of working, transmission of the power underground, greater adaptability for practically all classes of colliery work, and all-round efficiency and reliability, will prove sufficient warranty for the expenditure incurred. In proceeding to give some idea as to the probable cost of the installation of electrical generating plant, let it

be borne in mind that the figures given, although in some instances actual estimates, are intended merely to serve as a guide in "counting the cost" of an installation.

Let us suppose in the first place that boilers for the generation of steam have to be installed—although this in many cases may, of course, be unnecessary.

The boilers most generally in use for colliery work, where space is generally ample, are the Cornish boiler, the Lancashire boiler, and the Galloway tube boiler.

For high steam pressures the Stirling and Babcock & Wilcox water tube boilers are also sometimes adopted.

The Cornish Boiler is generally worked at pressures of from 40 to 60 lbs., and the horse-power varies from 50 to 100. It costs about £4 to £4, 10s. per horse-power, so that a 50 H.P. boiler would cost approximately £200, and a 100 H.P. boiler about £400.

The Lancashire Boiler is for larger powers, with steam pressures up to 100 and 120 lbs., and a horse-power of from 200 to 400 H.P., depending upon the size of grate area and the type of engine or engines to which steam is supplied.

Concerning the latter condition, it is quite obvious that the power developed in a boiler will very much depend upon the class of engine or engines using the steam generated. If the engines be of the slow-speed, non-condensing type, it is evident that more steam will be required per brake horse-power developed than if the engines had been high-speed, compound-condensing, or triple-expansion engines; and as the horse-power of a boiler is based on the actual B.H.P. of the engines to which it supplies steam, the adoption of the best types of engines adds to what might be termed the working capacity of the boiler.

A rule given by Percy in his *Mechanical Equipment of Collieries* is to the effect that the horse-power of a boiler may be got by multiplying the total grate area by five for good non-condensing engines, and by ten for compound condensing engines.

Thus, in a boiler having a total grate area of 40 square feet, the horse-power would be 200 in the former instance and 400 in the latter.

The price for a Lancashire boiler varies from £3 to £4 per horse-power, and the cost of a boiler and accessories 30 feet long by 8 feet in diameter, and for steam at 100 lbs. pressure, may be put down at anything from £600 to £700.

Water Tube Boilers are used for pressures above 120 lbs., and cost from £3 to £4 per H.P. according to the size.

Prime Movers

The types of engines most generally installed at collieries for the driving of electric generators may be given in the following order :—

1. Twin-cylinder coupled engines of the horizontal medium-speed type.

2. High-speed vertical engines of the single cylinder, double cylinder, or triple cylinder open or enclosed types.

3. Compound condensing and triple-expansion engines.

4. Steam turbines.

5. Gas and oil-engines.

6. Water turbines.

1. *Twin-cylinder Coupled Engines.*—This class of engine is very wasteful in steam consumption, and therefore uneconomical. For dynamo driving they are only adopted in cases where, through the cessation of other work, they have been thrown out of employment; and in that case their adoption for driving a dynamo of comparatively small output saves the purchase of new engines, and may be advantageous. This type of engine may, of course, be built for expansive working and with a condenser, when of course it would be much more efficient, but the compound condensing engine we have included in a separate section, and shall shortly consider its merits.

The coupled engine may cost anything from £2 to £4, 10s. per horse-power, according to the speed, and the efficiency varies from 70 to 85 per cent.[1]

2. *High-speed Vertical Engines.*—This type of engine is very efficient, and is perhaps more frequently adopted for actuating colliery electrical generating plant than any other type of reciprocating engine

The speed varies from 250 to 450 revs. per minute, and the engines are usually coupled direct to the generator.

The efficiency varies from 85 to 88 per cent., and the price per horse-power from £4 to £5, 10s.

3. *Compound Condensing and Triple-Expansion Engines.*—Compound condensing engines are a very economical and efficient class, the efficiency being usually about 85 per cent.

The speed is generally about 100 revs. per minute, but may sometimes be 150.

They cost about £5 per horse-power for high steam pressures. The triple-expansion type is also very efficient, and the price per horse-power is probably slightly less than in the case of the compound engine.

4. *Steam Turbines.*—Steam turbines are now being greatly favoured for large powers in colliery electrical installations. Turbines, of course, necessarily run at an enormous speed, varying from 2000 revs. per minute up to 4000 and 5000 R.P.M. They are said to be more economical than even the best of reciprocating engines, but are seldom adopted for generators of less than 300 kilowatts output.

The cost of a turbine installation runs about £5 per horse-power.

[1] Only the *mechanical efficiency* of the engines, it should be noted, is given in each case.

5. *Gas and Oil-Engines.*—Gas-engines cost from £6 to £10 per B.H.P., and are therefore more expensive in first cost than steam-engines, but, on the other hand, they are cheaper in the working. At collieries where much of the coal is coked, the gas given off in the process may be profitably utilised in the operation of gas-engine plant, and in such instances gas-engines may prove very economical.

The speed varies from 200 to 250 R.P.M. in engines up to 10 H.P., and from 160 to 200 R.P.M. in larger sizes.

Vertical gas-engines running at higher speeds than those above-mentioned are now being built, and are said to be very efficient.

The efficiency of the gas-engine varies according to the power of the engine, and is about 75 to 78 per cent. in the smaller sizes, and 85 to 88 per cent in the larger sizes.

The cost per horse-power also varies according to the power of the engine, engines of small power being more costly than those of large power.

For instance, an engine of 10 H.P. will cost about £8 per H.P., an engine of 50 H.P. about £6 per H.P., and one of 100 H.P. only £5 per horse-power.

Oil-engines are even more expensive than gas-engines in first cost, but are very economical in the working. The cost per horse-power runs on the average from £11 to £14.

The efficiency and speed is about the same as in a gas-engine of equal power.

Oil-engines are as yet but little used for dynamo driving at collieries.

6. *Water Turbines.*—A water turbine installation is fairly cheap as compared with a steam or gas plant.

A water wheel of 28 inches diameter and capable of yielding 50 H.P. will cost about £70, and one of 48 inches diameter and 150 H.P. will cost £180.

A Pelton wheel costs much about the same price; a wheel 30 inches diameter and 50 H.P. costing £65, and one 60 inches diameter and 300 H.P., £140.

It is only in comparatively few instances, however, that water-power is available at collieries in sufficient quantities to admit of a water-turbine or Pelton wheel installation being installed.

Generators, Motors, and Transformers

The continuous current dynamo costs from £8 to £2 per kilowatt, according to the size of the machine, the price per kilowatt gradually falling as the output increases.

Continuous current motors are slightly cheaper than the dynamos.

The following table (Table I.) gives sizes, prices, and efficiencies of a few machines :—

TABLE I.—DYNAMOS AND MOTORS.

Dynamos.		Motors.		Price.	Efficiency per Cent.
K.W.	R.P.M.	B.H.P.	R.P.M.	£	
1	1200	1½	1100	15	76
5	1000	6½	950	33	77½
15	900	17	850	68	79
35	900	39	850	116	86
75	800	90	750	195	91
150	550	190	500	330	94½
250	450	310	400	440	95

The armature costs nearly half of the price of the complete machine.

Alternating current generators cost slightly more than continuous current machines, the cost of the exciter helping to bring about the somewhat larger price.

For outputs ranging from 50 to 100 kilowatts, the price of the generator and exciter runs about £4 per kilowatt; from 100 to 200 kilowatts, about £3, 10s. per kilowatt; and from 250 kilowatts upwards, about £2, 10s. to £2, 15s. per kilowatt. These prices are for polyphase generators. Single-phase generators cost nearly 40 per cent. more.

Polyphase motors cost about the same as continuous current motors. Motors with short-circuited rotors cost from 5 to 15 per cent. less than machines with wound rotors. Single-phase motors cost about 40 per cent. more.

The periodicity varies from 25 to 50, and the speed from 1400 R.P.M. in the smaller sizes to 450 in the larger.

TRANSFORMERS

Transformers are necessary adjuncts in many low voltage and high-pressure circuits, and are valuable assets in long distance transmission underground, either for lowering the voltage in high-pressure circuits or increasing the pressure in currents of low voltage.

The average price for transformers runs from £2, 10s. to £3, 5s. per kilowatt.

A transformer for 100 kilowatts would therefore cost about £300.

CABLES

The price for cables is reckoned at so much per mile of cable, and depends upon (1) the current-carrying capacity of the conductors,

(2) insulation and covering, and (3) whether with armouring or without. The accompanying table (Table II.) is compiled chiefly from the list of the Corlett Engineering Company, Wigan, and gives some idea of the prices of different classes of cables.

The cables are all insulated with pure vulcanised rubber.

TABLE II.—PRICE OF CABLES (600 MEGOHM GRADE).

Size S.W.G.	Taped and Braided, Price per Mile.			Lead-covered, Price per Mile.			With Wire Armouring, Price per Mile.			Current carrying Capacity.
	£	s.	d.	£	s.	d.	£	s.	d.	Amperes.
1/19	15	0	0	20	0	0	29	0	0	1·256
3/20	25	10	0	32	5	0	43	10	0	3·016
7/19	44	10	0	54	0	0	69	10	0	8·708
19/17	154	0	0	185	0	0	218	0	0	46·27
19/16	189	0	0	223	0	0	261	10	0	60·39
19/15	228	0	0	270	0	0	314	15	0	76·50
19/12	445	0	0	492	0	0	562	10	0	159·5
37/16	328	0	0	375	0	0	425	10	0	117·6

If braiding and serving over the armouring is desired, the cables cost from 3 to 4 per cent. more than the above prices.

The 300 megohm grade of cable costs about 3 per cent. less than the 600 megohm grade, and the 2500 megohm grade about $4\frac{1}{2}$ to 5 per cent. more.

The price of concentric cables is about double that of single cables of the same size of wire.

As will be gathered from the table of prices given, the electric cable is an expensive medium of power transmission, and it will also be noted that the cost increases with the current-carrying capacity of the wires employed. In view of this, it is more economical to employ a current of high voltage and low amperage than one of low voltage and high amperage, as the cost of the cables necessary in the latter case is very much higher than in the former.

Cables insulated with vulcanised bitumen are slightly dearer in price than those having vulcanised rubber insulation, but are more durable.

The different methods of suspending and laying cables are described in another part of this work.

ELECTRIC LIGHTING

Incandescent lamps of any candle-power from 5 to 32 cost from 8d. to 10d. each. Lamps of 50 candle-power cost from 1s. 8d. to 2s. each.

Nernst lamps taking half an ampere at 100 to 200 volts cost

about 5s. each. In calculating the cost of installing electric lighting by incandescent lamps, a good rule is to allow from 18s. 6d. to 21s. for every lamp of 16 candle-power.

Where a separate plant is installed for lighting purposes alone, the power required in the engine will average about 9 horse-power for every 100 lamps of 16 candle-power.

Arc lamps cost from £3 to £4 each.

From the tables and quotations already cited it may be possible for the reader to arrive at a rough estimate as to the outlay incurred by the erection of colliery electrical generating plant, and also in the installation of the electrical parts of haulage, pumping, and other plant underground, together with the cost of the cables required to convey the power to the point of utilisation.

In order to draw a comparison between the cost of installing a gas-engine electrical generating plant and a turbine-driven plant of the same power, the following two estimates, Tables III. and IV., are given :—

Table III.—Cost of Electrical Plant to generate 1200 Horse-Power.[1]

Two gas motors, each of 600 horse-power, including pipe mains, erected complete	£8,000
One gas motor of 600 horse-power, in reserve, for use during cleaning, stoppages, etc.	4,000
Three dynamos, including pulleys	4,500
Switchboard	850
Two exciters	500
Foundations	600
Engine-house	1,250
Travelling crane, 15 tons capacity	600
Contingencies, say, 20 per cent.	4,060
Total	£24,360

The cost of a plant with turbines of the same horse-power as the two gas motors in Table III. would probably approximate the estimate given in Table IV. :—

Table IV.—Cost of Turbine Plant of 1200 Horse-Power.[2]

Buildings	£450
Steam turbogen, of 1200 horse-power	5,250
,, reserve, of 600 horse-power	3,000
Transformer, switchboard, etc.	650
Crane	150
Steam pipes	300
Duplicates, 10 per cent.	900
Boiler-house	2,500
Boilers	3,200

[1] *Trans. Inst. M. E.*, vol. xxxii. part iv. p. 369.
[2] *Ibid.*, vol. xxxii. part iv. p. 371.

Seating, chimney, etc.	800
Feed-pumps, steam separators, etc.	375
Contingencies	2,000
Total .	£19,575

The estimate for the gas-driven plant in Table III. reaches a figure which some may deem excessive, but the installation is a first-class one in every respect, and in installations of such magnitude it is better to err on the side of safety by erecting a plant excellent in workmanship and ample in power, than run the risk of breakdown and failure by installing a plant barely equal to the work in hand.

Both in the gas and in the turbine plants, the inclusion of reserve engines adds considerably to the total cost.

With larger installations the cost per kilowatt may be reduced considerably below this figure.

In Table V. are given the actual costs of electrical installations of 120, 550, 900, and 1800 horse-power.

TABLE V.—ACTUAL COSTS OF ELECTRICAL PLANTS OF 120, 550, 900, AND 1800 HORSE-POWER.[1]

Engine output . . horse-power	120	550	900	1,800
Electric output . . kilowatts	88	404	662	1,315
Cost of electrical plant : dynamo .	£375	£1,015	£2,650	£5,000*
,, ,, ,, switchboard	100	75		850
Totals . .	£475	£1,090	£2,650	£5,850
Plant-costs : purifying plant . .	£1,700	£1,650	£2,000	£3,000
,, gas-engine plant . .	2,145	4,889	7,225	14,450
,, electric plant . .	475	1,090	2,650	5,850
Totals . .	£4,320	£7,629	£11,875	£23,300
Plant-costs per kilowatt . . .	£49	£19	£18	£17

* Three machines.

COST OF WORKING ELECTRICAL INSTALLATIONS

Before entering into actual records of the cost of working electrical installations, some comparisons of motor and steam driving may prove interesting and at the same time highly instructive. Mr. A. J. Tonge[2] gives in Table VI. a comparison of the economy and efficiency of steam and motor driving.

[1] *Trans. Inst. M. E.*, vol. xxxii. part iv. p. 368.
[2] *Ibid.*, vol. xxix. part iii. p. 159.

TABLE VI.—COMPARISON OF MOTOR AND STEAM DRIVING.

Description of Plant.	Electric Driving.	Steam Driving.
Efficiency: electric horse-power or indicated horse-power and brake horse-power . .	0·82	0·85
Average electric horse-power at generator and calculated indicated horse-power at engine .	164	158
Steam consumed per hour per electric horse-power at generator and per indicated horse-power at engine . . . . pounds	19	56
Steam consumed per hour per brake horse-power at motors and per brake horse-power at engine . . . . . . pounds	23	66
Steam consumed per hour for 164 electric horse-power or for 158 indicated horse-power . pounds	3,116	8,848
Coal consumed per hour for 164 electric horse-power or for 158 indicated horse-power, calculated at the rate of 6·3 pounds of steam per pound of coal . . . . pounds	495	1,404
Ratio of coal consumption, electric to steam driving	1	2·8
Amount of coal consumption per year . tons	1,925	5,492
Cost of coal per year, at 5s. 6d. per ton . .	£529	1,510
Advantage on motor driving for 164 electric horse-power per annum	£981	...

Table VII., on page 130, furnishes another striking instance of the economic advantages to be gained by the substitution of electrical for steam power for practically every description of colliery work.

The ratio of saving is scarcely equivalent to that obtained in Table VI., but it is, nevertheless, considerable.

The cost of working electrical plant is probably the most satisfactory basis on which to argue the advisability of installing electric power at a colliery, and the two instances given above show that the saving over steam power may, in many cases, amount to a considerable sum. The following very interesting experiment, made by Mr. Percy C. Greaves,[1] shows the actual cost of producing electricity at a colliery under normal conditions:—

The plant used for the experiment consists of two 50-kilowatt generators, working at a pressure of 460 volts, and coupled directly to two Willans central-valve engines running at 460 revolutions per minute under a steam pressure of 100 lbs. per square inch. The boiler is attached to this plant alone, so that accurate results can be obtained. The period of trial covered one week.

The motors and machinery driven by the generators are as follows: One 24-kilowatt motor, driving a main-and-tail rope haulage-plant; one 1-horse-power motor, driving a centrifugal pump;

[1] *Trans. Inst. M. E.*, vol. xxxii. part iv. p. 363.

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one 42-horse-power motor, working a ram-pump; one 10-horse-power motor, operating a second ram-pump; one 15-horse-power motor, driving machinery in fitting-shops; and three Diamond coal-cutters, driven by motors of 20 horse-power each. In addition, there are 115 lights in the pit-bottom, coupled in series.

The two dynamos are run in parallel, and, at a certain period of the day, one is stopped and the other does the work alone. A self-recording watt-meter was put down to ascertain the number of units used by the plant. In one week, from Saturday night to Saturday night, 4400 units were consumed; during the same period, the boiler used 33 tons 12 cwts. of coal. The following stores were consumed by the plant: 9 gallons of engine-oil, $\frac{1}{2}$ gallon of cylinder-oil, and 2 lbs. of waste. The wages of the attendants,

Table VII.—Costs of Steam Power and Electrical Power at a Silesian Colliery.[1]

Description of Plant.		Power used.	Steam Power. Working Time during the Year.	Steam Power. Cost per Day.			Steam Power. Cost of Working.	Electrical Power. Working Time during the Year.	Electrical Power. Cost per Day.			Electrical Power. Cost of Working.	Saving.
		Horse power.	Days.	£	s.	d.	£	Days.	£	s.	d.	£	£
1. Haulage winches .	.	18	300	0	7	6	112	300	0	4	6	67	45
2. Rope haulage .	1	20	300	0	8	6	128	300	0	6	0	90	38
3. ,, .	2	20	300	0	8	6	127	300	0	6	0	90	37
4. ,, .	3	20	300	0	8	6	128	300	0	6	0	90	38
5. Ventilating fans	1	25	360	0	18	6	333	360	0	15	0	270	63
6. ,, .	2	60	360	1	10	0	540	360	1	4	6	441	99
7. ,, .	3	65	360	1	11	6	567	360	1	4	6	441	126
8. Screening . .	.	65	300	0	14	6	217	300	0	11	0	165	52
9. Centrifugal pumps	1	2	360	0	10	0	180	360	0	2	0	36	144
10. ,, ,,	2	2	360	0	10	0	180	360	0	2	0	36	144
11. ,, ,,	3	3	360	0	10	0	180	360	0	2	0	36	144
12. Belts . .	1	25	300	0	11	0	165	300	0	8	0	120	45
13. ,, . .	2	25	300	0	11	0	165	300	0	8	0	120	45
14. ,, . .	3	25	300	0	11	0	165	300	0	8	0	120	45
15. Coal hoists .	1	25	300	0	6	6	98	300	0	4	6	68	30
16. ,, .	2	65	310	0	15	0	232	300	0	11	0	165	67
17. Ash hoist .	.	4	360	0	2	0	36	360	0	1	0	18	18
18. Workshops .	.	23	350	0	5	0	88	350	0	5	0	88	0
19. Electric lighting	.	100	360	1	8	0	504	360	1	4	0	432	72
Totals . .	.	592					£4,145					£2,893	£1,252

[1] *Trans. Inst. M. E.*, vol. xxxii. part iv. p. 367.

one on each shift, were £2, 12s. The quality of the coal used was very inferior, 8 tons being bastard cannel, while 17 tons 17 cwts. of coal had been in stock for about two years, and, in Mr. Greaves' opinion, the full value of this fuel was 3s. 6d. per ton. Consequently, on this basis, the costs were as follow: Coal, 33 tons 12 cwts., at 3s. 6d. per ton, £5, 17s. 6d.; oil, $9\frac{1}{2}$ gallons, 18s. 6d.; wages, £2, 12s.; cleaning waste, 2 lbs. at 2d., 4d.; and the total cost of £9, 8s. 3d. is equivalent to 0·51d. a unit. In addition to this, there is the depreciation of plant and interest on the outlay.

A portion of this plant was bought when prices were high, so that it is hardly a fair criterion; but, taking the cost of the boiler, engine-house, and two plants at £2000, and allowing 15 per cent. for depreciation of plant and interest on capital, it would amount to £5, 15s. 4d. per week; and the cost of insurance of the dynamos is 2s. 6d. per week. The total cost will then become £15, 6s. 3d., or 0·83d. per unit. The trial was continued during the following week, when 4428 units were used, and the results were as follow: Coal, 34 tons 4 cwts., at 3s. 6d., £5, 19s. 8d.; oil, $9\frac{1}{2}$ gallons, 18s. 6d.; waste, 1 lb., 2d.; wages, £2, 12s.; boiler-cleaning, 4s.; interest, depreciation, and insurance, £5, 17s. 10d.; making a total cost of £15, 12s. 2d., or 0·83d. per unit.

A test was also made to ascertain how many units were used by the coal-cutter in normal working, and for this purpose all the lights and other motors were cut off, so that the watt-meter would register the actual energy taken by the Diamond coal-cutter. This machine was cutting in tough fire-clay on the floor-level to a depth of $4\frac{1}{2}$ feet, and it was running partly on the fourth, and partly on the fifth notch. The actual time taken was four hours, and during that period the machine cut 58 yards, or 87 square yards, and used 44 units, or 0·50 unit per square yard of cut, or 0·75 unit per lineal yard of cut. The actual yardage cut was certainly a record, and this may be attributed to the fact that the coal-cutter men knew that a test was being made, and they wished to do their best; but the writer does not consider that this would have any effect upon the cost per square yard in general cutting, because, when the machine is cutting, it will consume about the same amount of power. The coal-cutting machine was working about 1700 yards from the switch-board where the test was taken, and thus all losses by transmission were taken into account.

It may be explained that an electrical unit is 1 kilowatt-hour (1000 watts per working hour), and this is equal to 1·34 horse-power acting for 1 hour (see page 7). It was defined by Act of Parliament in 1882.

An induction test made by Mr. J. F. Lee[1] gave a somewhat lower cost per Board of Trade unit. The test was made on a generator of

[1] *Trans. Inst. M. E.*, vol. xxxii. part iv. p. 372.

225 kilowatts, actuated by a Robey cross-compound-condensing engine with a rope-driving connection to the generator. Separate boilers were used so as to arrive at the amount of fuel consumed, and the following results were obtained: Mean indicated horse-power, 407; mean electric horse-power, 298; loss in friction of engine, ropes, and generator bearings, 27 per cent.; and overall efficiency, 73 per cent.

The costs were as follow: Fuel, 7 tons of ordinary pit slack, made through holes, 1 inch square, at 4s. per ton, £1, 8s.; stores, 9d.; labour, 11s. 9d.; and the total, £2, 0s. 6d., were equal to 0·365d. per unit on the output obtained.

A third test, made by Mr. A. J. Tonge[1] on a turbine-driven plant, shows very interesting results. The generating plant comprises two Parsons turbo-alternators, supplied with steam from two Lancashire boilers, 30 feet long and 8 feet in diameter, at a maximum pressure of 150 lbs. per square inch. The boilers are provided with economisers. Each alternator has a normal capacity of 300 kilowatts. The load varies from a maximum of 247 kilowatts with a steam-consumption of 23 lbs. per kilowatt-hour to a minimum of 109 kilowatts with a steam-consumption of 28 lbs. per kilowatt-hour. With an average load the steam consumption is 25 lbs. per kilowatt-hour, or 19 lbs. per electric horse-power hour. Table VIII. records the results of three tests of the Parsons turbo-alternators:—

TABLE VIII.—RESULTS OF TESTS OF TWO TURBO-ALTERNATORS OF 300 KILOWATTS. THE AVERAGE READINGS ARE RECORDED.

No. of Test		1.	2.	3.
No. of machine		851	852	852
Load	kilowatts	314·4	311·2	106·5
Duration of test	minutes	150	202	122
Kilowatt-hours, No. 1 meter		383	512	95
Kilowatt-hours, No. 2 meter		406	545	120
Total kilowatt-hours		789	1,057	215
Power-factor		1	1	0·98
Volts		462	465	462
Amperes		391·1	383·3	137·5
Volt-amperes		782	1,039	218·9
Main field	amperes	9·6	11·3	9·8
Revolutions of turbine		3,010	3,040	3,060
Steam pressures per square inch	pounds	144	147	149
Vacuum at condenser	inches	26·2	26·7	27·65
Height of barometer	,,	30·05	30·0	30·0
Steam used per hour	pounds	6,996	6,837	2,991
Steam used per kilowatt-hour	,,	22·3	22·0	28·1
Steam used per electric horse-power hour	,,	16·6	16·4	21·0
Load on plant		Full	Full	One-third

[1] *Trans. Inst. M. E.*, vol. xxix. p. 156.

The test was continued in order to find out the loss of power in the cables through transmission to the various motors at work, and also the working efficiency of the motors.

The record is valuable as showing the percentage of power delivered from the dynamo which may reasonably be expected to be available in mechanical brake horse-power on the motor shaft.

Table IX. gives the results of the test:—

TABLE IX.—CABLE LOSSES AND MOTOR EFFICIENCIES.[1]

Work of Motors.	Haulage.	Screening Plant.	Pumps.	Ventilating Fans.	Other Fans.	Coal-cutters.	Small Motors.	Saw-mill.	Briquette Plant.	Totals and Averages.
Number of motors	3	2	4	3	4	3	4	1	2	26
Normal rating, brake horse-power	68	90	87	120	20	40	19	45	90	579
Average distance from generator . feet	1,230	216	402	1,371	282	3,234	288	255	1,110	924
Average working load, electric horse-power	30	48	71	100	16	49	13	26	83	432
Cable efficiency, the electric horse-power being unity	0·98	0·99	0·98	0·96	0·99	0·95	0·99	0·99	0·96	0·97
Motor efficiency, the electric horse-power being unity	0·68	0·76	0·86	0·86	0·80	0·86	0·80	0·85	0·88	0·84
Combined efficiency, the electric horse-power being unity	0·66	0·75	0·84	0·83	0·79	0·82	0·79	0·84	0·84	0·82
Average load in brake horse-power while working	20	36	60	82	13	40	10	22	70	353
Average continuous load on generator, electric horse-power	...	...	...	...	...	...	...	...	...	164
Maximum load on the generator, electric horse-power	...	...	...	...	...	...	...	...	...	329
Minimum load on the generator, electric horse-power	...	...	...	...	...	...	...	...	...	145

The cost of working the gas-power plant of 1200 horse-power, detailed in Table III., page 127, is given as follows:[2] The value of coke-oven gas may be taken at a low figure, because hitherto an equivalent

[1] *Trans. Inst. M. E.*, vol. xxix. part iii. p. 157.
[2] *Ibid.*, vol. xxxii. part iv. p. 369.

amount of heat obtained from gases has been set against the value of the fuel required to evaporate the same quantity of water. Comparing the value of a cubic foot of gas with bunker-coal worth 4s. 6d. per ton with a heat value of 15,000 units, the value is about 0·0033d., to which 0·0018d. should be added for working costs, interest, and depreciation, making together, say, 0·005d. per cubic foot of gas consumed in the gas-engine. The cost of gas for an engine consuming 10,000 cubic feet per hour will therefore be 4s. 2d. The other costs are attendance, cooling water, oil, and cleaning. The interest and sinking fund on a first cost of £20,000 may be reckoned at 7s. per working hour.

Table X. gives a summary of the cost of working the plant :—

TABLE X.—COST OF WORKING A GAS-POWER PLANT OF 1200 HORSE-POWER.

	s.	d.	s.	d.
Interest and sinking fund			7	0
Cost of gas	4	2		
Attendance	3	3		
Cooling water	2	4		
Oil	0	9		
Cleaning	0	6		
			11	0
Total . .			18	0

It will be noticed that the result gives a cost of 18s. per hour, or 0·18d. per horse-power hour.

The foregoing facts and figures relating to the cost of producing electricity at collieries, form, we imagine, very interesting and instructive reading, and will probably enable the mining student, as well as the colliery manager, to gather a practical estimate of the outlay incurred in the putting down of colliery electrical plant, and also the cost of working such a plant, compared with the steam-engine pure and simple.

Further records of actual tests of colliery installations might be given showing somewhat similar results to those already detailed, but sufficient has been said for our purpose, and a test conducted by Mr. W. B. Shaw,[1] and showing the costs of working the turbo-generating plant at Hulton Colliery, must suffice. The total capacity of this plant is 1000 kilowatts, and steam is supplied by four Lancashire boilers, 30 feet long and 8 feet in diameter.

[1] *Trans. Inst. M. E.*, vol. xxxii. p. 379.

TABLE XI.—COSTS OF WORKING TURBO-GENERATING PLANT AT HULTON COLLIERY

Year.	1904.		1905.		1906 (10 months).	
	Totals.	Per Kilo-watt-hour.	Totals.	Per Kilo-watt-hour.	Totals.	Per Kilo-watt-hour.
Weight of coal .	3,059 tons	5·3 lb.	3,298 tons	5·4 lb.	4,220 tons	4·4 lb.
Cost of coal at 5s. 6d. per ton .	£841	0·156d.	£932	0·163d.	£1,160	0·129d.
Wages . .	£466	0·087d.	£505	0·089d.	£581	0·064d.
Stores . .	£53	0·010d.	£80	0·014d.	£90	0·010d.
Interest at 5 per cent. and depreciation at 10 per cent. .	£1,691	0·315d.	£1,782	0·313d.	£1,996	0·222d.
Total cost . .	£3,051	0·568d.	£3,299	0·579d.	£3,827	0·425d.
Kilowatt-hours generated .	1,289,000		1,366,000		2,164,000	
Load-factor * .	0·54		0·49		0·45	

* The load-factor is the proportion of the average load to the maximum load during the year.

CHAPTER VII

ELECTRICITY APPLIED TO COAL-CUTTING

Advantages and disadvantages of electrical coal-cutters as compared with compressed air machines—Arguments for and against the adoption of coal-cutting machinery—Advantages of machine-mining over hand-holing—Objections to electrical coal-cutting machinery—Conditions best suited to machine coal-cutting—Control of the roof—Position of undercut—Depth of cut—Shallow undercut—Deep undercut—Stone-holing *v.* coal-holing—Comparative costs of machine-holing in stone and in coal—Direction and length of machine face—Comparative costs of machine-mining with gate roads differently spaced — Machinemen — Stowers — Gummers—Timbermen and fillers—Types of electric coal-cutters—The Pick machine—Revolving-bar machines—The "Pickquick" machine—The Hurd coal-cutter — Disc machines — The Diamond coal-cutter — Anderson-Boyes electric coal-cutter—The Crescent machine—Performance of a Crescent coal-cutter—The Jeffrey disc machine and other disc coal-cutters—Electric coal-cutters of the chain type—The Goodman electric chain coal-cutter—Jeffrey chain machine—Anderson-Boyes chain machine—The Diamond patent longwall chain machine—The Jeffrey electric shearing machine—Goodman low-type breast machine—Power truck—The Stanley heading machine—Power consumed by coal-cutting machines—Cost of electric driving of coal-cutters—Haulage arrangements—Gate-end panels—The trailing cable—Coal-cutter motors—Cost of coal-cutting machines.

Coal-cutting by machinery has made rapid strides during the last few years, and must unquestionably continue to do so in the future.

At the first introduction of coal-cutting machines into mines, compressed air was greatly in the ascendency as the motive power, but by degrees the advantages of electricity over its formidable rival became apparent, and the number of new machines driven by electrical energy rapidly increased, until at the present time there are nearly as many coal-cutting machines driven by electric motors as there are driven by compressed air.

The advantages of electricity over compressed air for driving coal-cutting machinery are many, and the disadvantages comparatively few.

The advantages, so far as the transmission of the power from the surface to the point of utilisation is concerned, are well known, and will be found fully discussed in another part of this work.

Less time is occupied in the attachment of the trailing cables than is necessary in laying the pipes and coupling to the machine in the

case of compressed air, the speed of cutting attained is greater, and the general efficiency of the electro-motor-driven coal-cutter is higher than in the air-driven machine.

The disadvantages of the electrically driven machine are practically confined to the recognised dangers arising out of the use of electricity underground, and especially in fiery mines.

Arguments for and against the Adoption of Coal-Cutting Machinery

There are many advantages which may accrue, not only to the mine owner, but also to the miner, from the use of coal-cutting machinery. The innate antagonism of the average miner to the introduction of the "Iron Man," although perhaps but the outcome of quite a natural jealousy, is nevertheless wholly uncalled for and altogether unreasonable. Indeed, in not a few instances the introduction of coal-cutting machinery has been the means of raising the average daily wage throughout the colliery, while at the same time it has proved most advantageous to the owners of the mines.

There are many seams of coal at present being mined at a profit which, owing to their thinness, the hard nature of the undercutting, and the consequent difficulty in getting the coal, could not be profitably worked solely by hand labour, and would perhaps have had to be altogether abandoned were it not for the coal-cutter and associated appliances.

Some of the advantages which machine mining may be said to possess over hand-holing are:—

1. Capability of working at a good profit certain seams of coal which, if worked by hand, would probably yield little or no recompense to the mine owner.

2. Greater percentage of round coal got (especially in soft seams) than can be secured by hand labour. This advantage results from the greater depth of holing that can be attained with the coal-cutter, and is also partly due to there being less coal cut away in the process of machine-holing than where the holing is done by hand.

The authors have noted one particular seam—coal very soft, with hard roof and floor—where not more than 30 per cent. of round coal was secured when worked by hand, but when coal-cutters were introduced the proportion of round coal was increased to over 70 per cent.; and this was attributed to the much greater depth of holing which the coal-cutter could reach ere the coal fell.

3. A greater output of coal per man employed.

4. Greater and more uniform "rate of advance" of the working faces is secured, with the result that the roof is easier to maintain and the weight is kept more constantly thrown forward on the coal face—the coal, in consequence, "breaking" more readily when holed.

5. More highly organised division of labour is attainable. By this we mean that, where coal-cutting machines are in use, the different operations incident to coal-getting may be more easily classified, and a special class of men delegated to undertake each class of work independently. One gang of men, for instance, do the actual "getting" of the coal, another section the filling of the coal into tubs, another the timbering, another the stowing, another attend to the machinery, and so on.

Where such division of labour is carried on, and organisation is efficient and complete, economic advantages must certainly follow.

Where the coal is got solely by hand labour, however, organisation on such lines, though sometimes attempted, is seldom successfully carried out, and the man who "gets" the coal has generally also to do the filling, timbering, stowing, etc.

Some of the objections which may be raised against the adoption of electrical coal-cutting machines are :—

1. The dangers attached to their use in fiery mines.

2. Dangers of "live" motor casings, abrasion of insulation of trailing cables, etc.

3. Necessity for specially qualified men to attend to and repair machines.

4. The great noise made by the machines in working. The operators at the machines cannot hear any breaking or movement of the roof or coal face while the coal-cutters are at work, and the machines have to be stopped for a few minutes at frequent intervals in order to allow of an examination of the state of the roof and coal face being made. Obviously, there is here some little extra danger attached to the use of coal-cutting machines, but of course this danger is common to all coal-cutters, whether electrically driven or otherwise.

5. Necessity for keeping the working places "wide" to allow of the passage of the coal-cutter along the face, rendering the machines unsuitable for very tender roofs.

In spite of these objections, coal-cutting by machinery possesses advantages over hand labour which cannot be gainsaid, and for suitable coal seams their adoption is generally decided upon with little cavil.

Conditions best suited to Machine Coal-Cutting

Before deciding upon the introduction of coal-cutting machines to work any coal seam, a variety of circumstances have first to be considered.

Some coal seams are very suitable for the adoption of coal-cutters, while others are not so suitable, and some, indeed, are entirely

unsuitable. It is not so very easy a matter to say which coal seams are suitable for machine work and which are not suitable.

The authors have seen coal-cutting machines worked successfully under a variety of circumstances and conditions. We have known them to give satisfaction in very hard seams with no clay holing and a fairly strong roof, in very soft seams with a hard rock roof and floor, in moderately hard seams with clay holing and only a fairly good roof, and in both thin and thick seams.

The adoption of coal-cutting machinery does not depend so much upon the section of the coal seam as upon the nature of the roof and floor.

If a coal seam has a very tender roof, difficult to keep and requiring much timber, the profitable introduction of coal-cutting machinery may be said to be well-nigh impracticable. Again, if the seam worked is traversed by well-defined facings, or slips, and owing to the direction of dip, etc., it is not found advisable to have the line of working face at right angles to the line of slip, it will be found a very difficult matter indeed to keep the roof where coal-cutting machines are in use, owing to the necessity for keeping the places "wide" to allow of the passage of the machine.

In such circumstances, falls of roof would probably be very frequent, obstructing the passage of the coal-cutter along the working face, and, it may be, burying the machine itself.

The nature of the floor is of much less moment than the nature of the roof, and coal-cutting machines are now at work on all sorts and conditions of pavements.

For soft pavements, the machine, along with the skids, is generally mounted upon a steel plate, about $\frac{3}{8}$ to $\frac{1}{2}$ inch in thickness, and slightly turned up at the front and rear. This arrangement suffices to prevent the machine from ploughing into the pavement. For heaving pavements, efficient stowing and rapid "rate of advance" are about the best and most practical preventatives.

Probably the most favourable circumstances under which a coal-cutter can be worked are where the coal seam to be machined is very hard and strong, with no suitable holing and a good strong roof.

The working of such a seam by hand would probably require a very high tonnage price, and it is in such high-priced seams that coal-cutting machinery has been, and will be, most successful. In very thin seams, too, the coal-cutting machine is generally very successful.

In such seams the undercutting and getting down of the coal is rendered much more difficult and arduous than usual by the lowness of the roof, and with coal-cutting machines the coal can be undercut to a great depth, often as much as 4 to 5 feet, and the coal is thus enabled to break by its own weight.

In such thin seams an electrically driven coal-conveyor is frequently used in conjunction with one or more coal-cutting machines, and this arrangement generally proves very economical.

Then, again, coal-cutting by machinery has often proved eminently successful in very soft seams, with hard roof and floor, not so much because of any appreciable reduction in the price of getting, but principally owing to the much larger proportion of round coal that could be secured.

Coal-cutting machines, then, may be said to be suitable for thin seams with a good roof; soft seams with a good roof; hard seams with a good roof; seams having little or no dirt for stowing, with a good roof; seams making plenty stowing material, with only a moderately good roof; and for seams of any inclination, except, it may be, very steep seams.

The above, although classed as the most suitable seams for being worked by coal-cutters, are not, of course, the only seams which may be profitably machined. There have been numerous other coal seams which, although not providing the same glowing prospects at first consideration as those we have discussed, have nevertheless been so skilfully engineered and worked that success has attended the venture.

Control of the Roof

The adoption of coal-cutting machinery very often introduces the necessity for special methods of timbering. A passage must be left along the face for the progress of the coal-cutter, so that props cannot be set within 4 to 5 feet of the coal face.

Where the roof is tender, and perhaps traversed by frequent slips or breaks, the method of timbering generally adopted is on the following principle:—

Every 4 feet or less a setting of timber is fixed, consisting of light bars set or "needled" into the coal face at one end and resting on upright props at the outer end. After the machine has passed by, temporary supports are set in the middle of the bars. The coal is taken off in about 6-feet lengths, and as soon as it has been cleared away, props are set on the exposed ends of the bars, and the temporary middle supports are then knocked out.

The "cocker-sprag" may also be used to good advantage in many instances. The "cocker-sprags" consist of props laid longitudinally along the coal face and gripped by short sprags from the roof and floor. They make not only safe holing props but good roof supports as well. Of course, they can only be set behind the coal-cutter, and have to be withdrawn when the coal is about to be taken off.

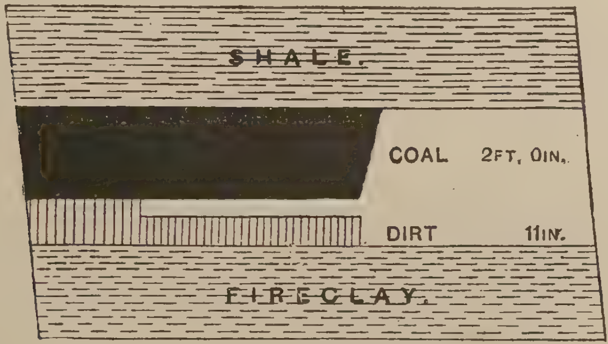
The use of coal-cutting machines usually enables a more

thorough application of systematic timbering to be carried out as the result of the rapidity of advance, straightness of the line of face, and regularity of subsidence of the roof.

Frequently, where there is a scarcity of stowing material, a considerable quantity of the back timber is withdrawn so as to allow the roof to subside in the goaf. This has the effect of easing the pressure on the roof next the working face, rendering it more easy to keep.

Where there is a sufficiency of dirt and stones, however, the waste should be thoroughly and systematically stowed.

As a rule, the increase in the rate of advance secured by means of the coal-cutting machine proves a great help in the keeping of a troublesome roof; and this advantage may probably



DEPTH 70 YARDS. INCLINATION 1 IN 11.
UNDERCUT 4FT. 6IN. BY ELECTRIC MACHINE.

FIG. 82.

outweigh the difficulties arising from the necessity for having the places "wide" next the coal face.

Position of Undercut

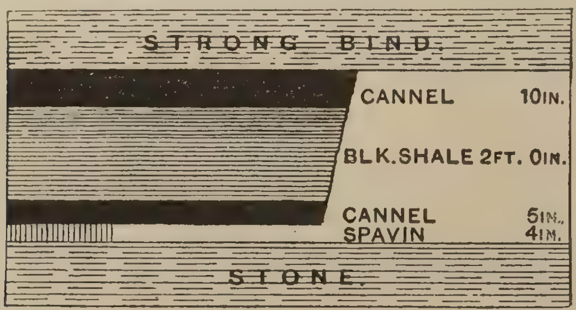
The position of the holing may be at any point between the floor of the seam and the roof.

The main factors in determining the most suitable position are the relative hardness of the strata forming the seam section, and the nature of the partings between each stratum.

The most frequent position is next the floor of the seam, and if the holing can be done in a suitable dirt band, and there is a good parting next the roof, that position is perhaps the most to be desired.

If the bottom stratum of dirt or stone be too hard to cut, the holing is sometimes done in the bottom of the coal itself.

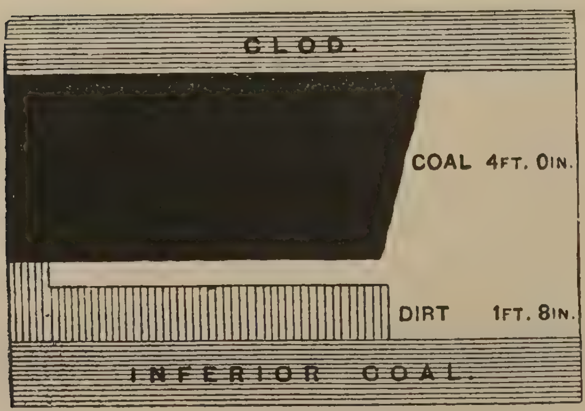
If the holing is done in a layer of fireclay or dirt, a point to be



DEPTH 80 YARDS.

UNDERCUT 4FT 6IN. BY ELECTRIC MACHINE.

FIG. 83.



DEPTH 135 YARDS.

UNDERCUT 7FT. 0IN. BY POLYPHASE ELECTRIC MACHINE.

FIG. 84.

watched is that the coal above remains firm until the dirt band has been cleared away; else, if part of the coal drops away and gets mixed with the dirt, great trouble will be experienced in securing it free from dirt admixtures.

If the holing is to be done above the coal, there should be a good parting next the floor of the seam.

Figs. 82 to 87 show some sections of coal seams in which the position of the holing is varied to suit the conditions peculiar to each case.

Figs. 82, 83, and 84 illustrate seams worked by the Diamond disc

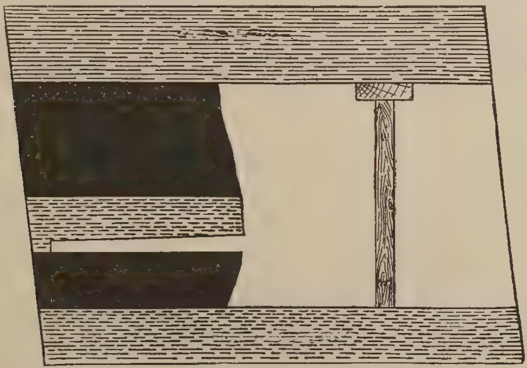


FIG. 85.—Holing 1 ft. 6 in. from floor.

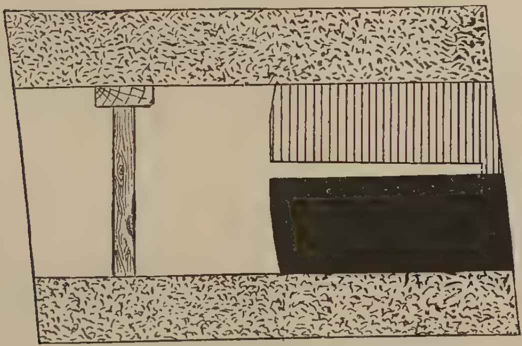


FIG. 86.—Holing 2 ft. 9 in. from floor.

coal-cutter, while the sections shown in Figs. 85, 86, and 87 are being worked at present by the "Pickquick" bar machine.

DEPTH OF CUT

The most suitable depth of undercut is often a matter not easy to determine.

Mature consideration must be given to every condition which

exerts an influence on the point at issue ere any attempt is made to come to a decision in the matter. Some of the points which fall to be discussed are: (1) the nature of the roof, (2) the hardness or softness of the coal, (3) the depth at which the coal most readily breaks, (4) the height of the seam, and (5) the time taken to clear away the coal with a certain depth of cut.

The first point mentioned, namely, the nature of the roof, is of primary importance. If it be of weak character, a great depth of undercut might prove ruinous so far as the maintenance of the roof is concerned.

The breaking depth of the coal is also of little less moment. If the coal breaks at a depth of undercut reaching 5 feet, and the

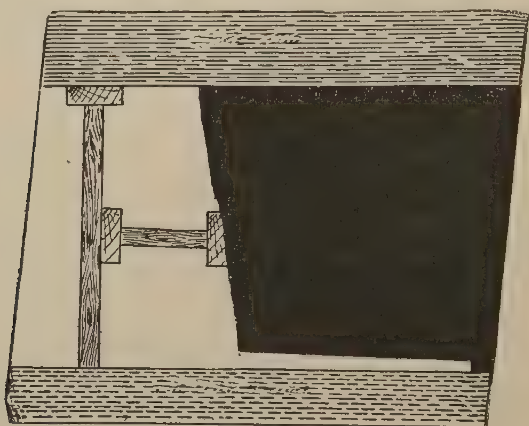


Fig. 87.—Undercut by polyphase machine.

machine is set to cut to a depth of only 4 feet, the coal may refuse to break voluntarily, and in consequence may have to be blown down by means of explosives at considerable expense.

The breaking depth of the coal, however, is not so very difficult to determine, as its value may be suitably determined by hand-holing; besides, even if it required an undercutting of 5 feet or more to bring down a coal when the holing was done by hand, it may safely be assumed that, with machine undercutting, the coal will break at 6 inches or even a foot less depth of holing, as the result of the greater rate of advance of the face, with the consequent greater and more uniform pressure of the roof on the seam.

Then, again, the hardness of the coal is a matter which goes a long way in determining the depth of cut.

Soft seams will generally, of course, break readily with even a

very shallow undercut, but it is much better to undercut a soft and friable seam to a good depth, because of the larger percentage of round coal which is thereby obtained.

In thin seams, too, a deep undercut is frequently adopted, as, owing to the coal being of comparatively little weight in itself, it has usually to be holed to a good depth ere it will break of its own accord.

The minimum depth of undercut may be put at 3 feet, as no advantage can be reasonably expected to accrue from a shallower cut.

A brief enumeration of the relative advantages of the shallow and of the deep undercut may be profitable.

Shallow Undercut

(1) A lighter and consequently less expensive machine may be used; (2) more suitable for a weak roof than a deep undercut; (3) the coal is more quickly cleared away; (4) less time elapses between each passage of coal-cutter across the face; (5) uniform daily rate of advance of face; and (6) breaking down of the roof is of less frequent occurrence.

Deep Undercut

(1) More suitable for a hard coal with a good roof; (2) more suitable for a soft friable coal, owing to the larger percentage of round coal obtainable; (3) there is a greater quantity of coal got per run of the machine; (4) where the gate roads are a distance apart, and a road is taken along the face to facilitate the filling of the coal, an advantage accrues from having a deep cut, in that more coal is filled for the one laying of the track; and (5) getting machine into position, changing cutters, and other operations incidental to the working of coal-cutting machines, occupy less time for the same area of cutting done.

It is probable that a medium undercut of, say, 4 to 4½ feet, may combine many of the advantages of the shallow and deep undercuts.

Stone-Holing *v.* Coal-Holing

The nature of the material in which the undercutting of a seam is done often goes a long way in determining the economic advantages to be gained from the employment of a coal-cutter.

In thin seams especially there is a natural reluctance to kirve away the precious mineral, and, if it be at all practicable, an attempt is generally made to do the holing in the band of stone, either above or below the coal, if such a stratum exists.

Now, this arrangement is both practical and, if the holing be of a

soft nature, extremely economical. But, on the other hand, if the stratum of stone be very hard and of a sandy nature, the advantages of cutting in the stone instead of in the coal are not so readily apparent, and the most suitable position for the undercut becomes a matter for serious consideration. In hard, sandy material the machine cutter-picks will not endure for long, and the speed of cutting is also exceedingly slow.

Consequently, having regard to the comparatively slow rate of progress, the necessity for frequent renewal of cutter-picks, and the undue wear and tear on the machine, it may frequently be more economical to perform the undercutting in the seam itself, even although a considerable percentage of the coal is practically lost as the outcome.

The following example shows the comparative costs of machine-holing in stone and in coal:—

Comparative Costs of Machine-Holing in Stone and in Coal.[1]

	Holing in Stone—Actual.	Holing in Hard Coal—Estimated.
Results:—		
Average distance cut per shift	30 yards.	60 yards.
Average output per shift	27 tons.	54 tons.
Proportion of round coal	60 per cent.	53 per cent.
Selling value of output—round coal, at 7s. 6d. per ton	16 tons 6 cwts.	28 tons 14 cwts.
Selling value of output—small coal, at 2s. 6d. per ton	10 tons 14 cwts.	25 tons 10 cwts.
Selling value of output—totals	£7, 10s. 6d.	£13, 19s.
,, ,, averages, per ton	5s. 6½d.	5s. 2d.
Costs:—		
Machine labour, at 19s. per shift, per ton	8·50d.	4·25d.
Power	1·00d.	0·50d.
Cutters, oil, etc.	1·00d.	0·50d.
Repairs	1·50d.	0·75d.
Stowing dirt	1·00d.	0·00d.
Interest and depreciation on coal-cutter, cables, etc., at 18 per cent. per annum	2·85d.	1·43d.
Totals	1s. 3·85d.	7·43d.
Summary:—		
Saving in cost by holing in coal, per ton		8·42d.
Reduction in average value of output, per ton		4·50d.
Nett saving in cost by holing in coal, per ton		3·92d.
Gain of output, per shift		20 tons.
Reduction of oncost by the doubled output from the seam, per ton		50 per cent.

[1] *Trans. Inst. M. E.*, vol. xxxi. p. 378.

Direction and Length of Machine Face

The direction or "lie" of the machine face depends upon various circumstances.

If the seam lies at a slight angle of inclination it is sometimes considered best to have the machine-face parallel or almost parallel to the line of full dip, with headings to the "rise," say, every 50 or 60 yards, and gate roads running level course, off the headings, at intervals of from 10 to 12 yards.

In seams above 4 ft. 6 ins. in thickness this method works admirably.

As only a single line of rails is necessary in the gate roads, the latter may be kept very narrow, and consequently, if the roof is none too strong, the narrow roads are much easier to maintain than would be headings to the "rise" necessitating a double road. Considerable saving in timber and repairs may thus be sometimes effected.

Another system which is very popular in Scottish mines, and has much to commend it, is to have the line of machine face running

Comparative Costs of Machine-Mining with Gate Roads spaced 22½ Yards and 15 Yards apart; Seam, 2 Feet 9 Inches thick; and Undercut, 3 Feet 9 Inches deep.[1]

	I.	II.
Distance between gate roads . yards	22½	15
Length of face yards	135	135
Coal undercut per cutting shift . tons	130	130
Number of gate roads .	6	9
Coal per place . . tons	21·5	14·2
Fillers per place . .	2	2
Output per filler per shift . . tons	5¼	7
Total output filled per shift . . tons	65	130
Time required to clear face . shifts	2	1
Output carried per gate road per shift . tons	10·5	14·2
Face advanced per working day . feet	1⅞	3¾
Proportion of small coal . . per cent.	23	20

	I.	II.
Costs per ton—		
Machine labour .	2·0d.	2·0d.
Getting and filling .	1s. 5·0d.	1s. 1·0d.
Tramming . .	1·0d.	1·0d.
Heading and day work . . .	1·0d.	1·0d.
Electric supply and cutter-picks .	1·0d.	1·0d.
Repairs to coal cutter . . .	0·5d.	0·5d.
Interest and depreciation of coal cutter . . .	1·2d.	0·6d.
Ripping roads .	4·0d.	6·0d.
Maintenance of roads . . .	1·0d.	0·5d.
Underground oncost	6·0d.	3·0d.
Totals . .	2s. 10·7d.	2s. 4·6d.

[1] "Practical Problems of Machine-Mining," by Mr. Sam. Mavor, *Trans. Inst. Min. Eng.*, 1904, vol. xxxi.

level course, with headings to the "rise" at intervals of anything from 10 to 20 yards.

The headings are branched off main levels, and are allowed to run from 50 to 60 yards, when other levels are set away higher up and nearer to the working face.

The principal advantage to be gained from laying out the workings after this fashion is a greater possible output per man, due to the fact that the face, as far as possible, is always at a minimum distance from the main haulage roads, and the cost for hand drawing is, in consequence, comparatively little.

Other considerations, such as the line of cleavage, the line of face resulting in the production of the maximum proportion of round coal, the keeping of the roof, etc., must, of course, influence to a great extent the most profitable direction of machine face.

The table on previous page shows the comparative cost of machine-mining in two instances with the gate roads differently spaced.

The following additional particulars relative to the working of coal-cutting machines under varying conditions, being records of actual cases supplied to the authors, may be found of special interest:—

Section of Seam worked by Coal-Cutter.

Blaes, 3 to 8 feet	Strata composing roof.
Black stone, 1 foot	
Inferior coal, 9 inches . . .	
(Roof) stone (soft), 10 inches . .	
Height of seam as worked, 5 feet 1 inch	Coal, 2 feet 10 inches. Stone, 7 inches. Coal, 1 foot 8 inches.

Rock pavement.

The machine face lies level course, and the system of "laying-out" adopted is that of main levels with headings direct to the rise at short intervals apart. The headings are allowed to run a distance of about 60 yards, when they are cut short by a new main level higher up the seam.

The coal-cutter used is of the "Pickquick" type, the motor being of 22 B.H.P., and taking from 30 to 35 amperes at 450 volts in ordinary working.

The following are some particulars relating to the working of the machine:—

Total length of machine face . . .	112 yards.
Distance between headings . . .	16 ,,
Number of headings . . .	7
Width of headings . . .	9 feet.
Number of men in each heading * .	3
Output per heading per shift . .	13 to 14 tons.

* Men do stowing in addition to filling the coal.

Number of machinemen	3
Number of men "gumming" machine	3
Output from "gummers" per shift	15 tons.
Duration of cutting shift	$10\frac{1}{2}$ hours (about).
Average duration of actual cutting	$7\frac{1}{2}$,, ,,
Average loss of time from stoppages, breakdown, etc.	3 hours.
Position of holing	Floor level.
Nature of holing	Coal (hard).
Depth of holing	4 feet.

Particulars of Working of Hurd Bar Machine at a Fifeshire Colliery.

Length of machine face	120 yards.
Number of headings	10
Distance apart	12 yards.
Width of headings	9 feet.
Number of men in each heading	2
Output per heading per shift	$14\frac{1}{2}$ to 15 tons.
Total output from machine per shift	150 tons.
Number of machinemen	3
Number of stowers	6
B.H.P. developed in machine	18 to 20.
Voltage	450
Amperes	28

In addition there are three men required to drill shot-holes, and also one shot-firer.

The seam is of the following section :—

Soft blaes	3 to 12 feet.
Top coal	2 feet 6 inches (*roof*).
Bottom coal	3 ft. 11 ins. (*seam worked*).
Strong band of friable sandstone, which collapses immediately on being cut	7 inches (about).
Inferior coal	3 ,,
Fireclay (in which holing is done)	4 ,,

The cutter bar was seldom damaged and very little retarded by the continual collapse of the sandstone.

In thin seams a considerable saving may often be effected by the employment of electric coal-conveyors.

The gate roads need only be at distances apart varying from 50 to 100 yards, and this certainly means a great saving in thin seams where a thick brushing must be taken down in all roads in order to obtain sufficient height for tub-filling. The machine face may be of any length, according to the cutting capacity of the machine, the number of machines at work, the time required to clear away the coal, and the system of working best adapted to the nature of seam and roof.

If only one machine is in use, and one filling shift is able to clear away the coal produced, then the length of machine face should

correspond with the realised cutting capacity of machine, some slight allowance being made for stoppages, repairs, etc.

Where circumstances permit, this is perhaps the best arrangement of all, as it lends itself to regular output and uniform daily advance of face, with the consequent obvious advantages.

Where more than one machine is at work under conditions similar to above, the machine face may be lengthened accordingly, one machine commencing to cut where another leaves off.

If it is found that two filling shifts are required to clear away the coal produced by one machine, the face should be twice as long as the machine can cut in one shift, in order to allow of the machine being at work regularly every night.

Another arrangement is to have two or more machines following each other across the same face, the coal undercut by each machine being, of course, taken down and cleared away ere the following one comes along.

Division of Labour

1. *Machinemen.*—As a rule three men are necessary to manage each machine—one to be constantly in attendance at electrical end of coal-cutter, to start, stop, regulate, or reverse; another to watch at cutter end, keep cutter clear of fallen coal as far as possible, and assist in preparing the ground beyond for the advance of the machine; and a third to set suitable props, knock out others if necessary, arrange battens, etc., to accommodate skids, and generally to clear and prepare the way for the advancing coal-cutter.

2. *Stowers,* "*Gummers,*" *and Timbermen.*—If the holing is done in a band of dirt or stone which readily parts away from the seam, it is generally thought a good arrangement to have a gang of men termed "stowers," who clear away the rubbish into the waste before the coal is taken down.

The stowers very often do the timbering of the places in addition.

Where the coal is clean throughout, stowers are, of course, unnecessary. If the holing is done in the coal, "gummers" are sometimes employed to clear away the "gum" or holings made by the machine. The "gum" is thus kept separate from the round coal, and is generally used for the boiler furnaces.

3. *Fillers.*—The number of fillers necessary to clear away the coal produced by a machine depends principally upon the thickness of the seam and the expedition with which the full tubs can be removed and replaced by empty trams.

In a seam 4 to 5 feet thick, one machine may produce anything from 120 to 200 tons per shift, and one man and a boy, under favourable conditions, can generally cope with from 35 to 40 tubs of coal, each containing from 7 to 8 cwts.

This would give an output from each man and boy of from 13 to 15 tons per shift.

Ten men and ten boys would thus be capable of coping with from 130 to 150 tons per shift.

The fillers generally contract to fill away the coal only, and to run the tubs down the headings to the levels, and have nothing to do with stowing, timbering, etc.

Types of Electric Coal-Cutters

Coal-cutting machines are generally classified according to the nature of their cutting appliances, and electrical coal-cutters may be divided into the following four distinct classes :—

1. Pick or puncher machines, in which the coal is chipped away by a succession of rapid blows.
2. Revolving-bar machines, which cut or grind away the coal.
3. Disc or circular saw machines, which also cut away the coal, but in which the teeth are fixed on the circumference of a horizontal wheel instead of a tapered bar.
4. Chain machines, in which the cutters are attached at intervals to the links of an endless chain.

In deciding which of the four types to adopt, the principal points to be considered are: (1) Speed of cutting as proved by attested records of actual performances in different seams, (2) strength of machine and the working parts especially, (3) liability to or freedom from breakdown, (4) adaptability to different and differing conditions, (5) ease with which repair and renewal of parts can be effected, (6) noise made whilst working, and (7) convenience of changing and refitting cutter-picks.

The revolving-bar and the disc coal-cutters most satisfactorily fulfil the requirements of a reliable machine, and are probably the best of the four types, although the chain machine has also proved very successful under certain conditions.

In describing the different makes of machines included in each type, some particulars of actual performances will be given which may enable a truer estimate to be formed of the respective merits of the various machines.

The Pick Machine

Although there are many excellent pick machines in use for machine-mining at the present moment, practically the whole of them have compressed air as the motive power, and there is really only one successful machine of the puncher type at present on the market which derives its energy from the electric current; and even this ingenious machine cannot be said to be entirely

motor-driven, as it owes much of its practical adaptation to a clever mechanical combination of spring and cam.

The comparatively few attempts that have been made to produce a really successful electric pick machine, may be said to be principally due to the great mechanical and electrical difficulties that hamper the production of a reciprocating motion within the small compass necessary in a handy coal-cutting machine. The inventors of the Morgan-Gardner pick machine, which is the one above referred to, are perhaps the only patentees who have successfully overcome these many difficulties, and placed at the service of the mining world a coal-cutter of the puncher type which possesses the indispensable advantage of handiness and efficiency.

In the Morgan-Gardner machine (see Fig. 88) the motor is situated at the rear end of the machine carriage. Through bevel and spur gearing the motor imparts a circular motion to a cam mounted on a suitable shaft.

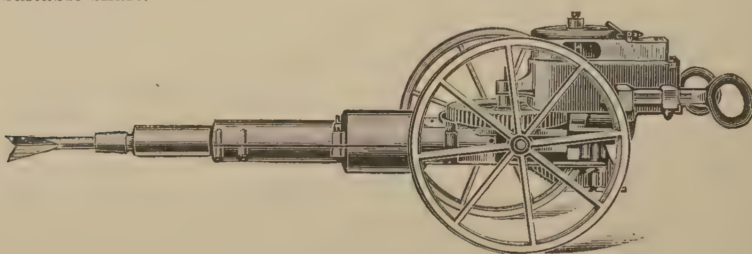


Fig. 88.—Pick machine.

The action of the machine is simple and easily understood, and is as follows :—

The reciprocating piston, which works in a suitable casing, is caught by the revolving cam and drawn back in the cylinder against a powerful spiral spring fixed at the back of the casing. The piston, forced by the motor-driven cam, compresses the spring to a high tension, and on the cam slipping the piston, which is made to occur at the termination of the backward stroke, the spring in regaining its natural position shoots the piston with terrific force to the other end of the cylinder. Here the cam again catches it, and draws it back as before.

The stroke of the piston is about 8 inches, and it runs from 175 to 225 complete strokes per minute.

The machine is 7 feet long, 21 inches wide, and weighs about 750 pounds.

It is mounted on a light steel carriage, by means of which it can be conveniently and expeditiously removed from place to place.

The motor is adapted for continuous current, and the armature is of

the toothed gramme ring type, with the coils wound below the surface. The machine is very suitable for working in pillar and stall headings and rooms, main levels, main intake and return air-ways, and all classes of narrow work.

It is said to be capable of cutting a lineal distance of 60 feet, $4\frac{1}{2}$ feet under, in a shift of 9 hours, and it requires only two operators.

Revolving-Bar Machines

The revolving-bar type of machine lays claim to be the strongest and most reliable of all the types of coal-cutters, and this claim rests on the fact that the cutter, being a tapered solid bar of nickel steel, is mechanically stronger and less likely to give trouble than the revolving wheel of the disc type or the endless chain of the chain machine.

The bar machine undoubtedly possesses a notable advantage is the working of soft, friable seams, which readily fall when undercut.

In such seams the falling coal would get between the spokes of the revolving wheel in the disc machine, obstruct its passage, choke the motion of the disc, and probably cause derangement or breakage of some of the working parts, if the machine were not immediately stopped and the coal cleared away.

In the same way the fallen coal would obstruct the motion of the endless chain in the chain type of coal-cutter, necessitating the stoppage of the machine and the clearing away of the coal as before. On the other hand, the revolving bar crushes its way through the falling coal with little or no damage at all to the cutting tool. In the case of the disc machine the use of a solid disc may of course obviate to some extent the risk of damage from falling coal.

If in the process of undercutting some hard substance be met with, the bar machine is probably able to cut through the obstacle with less risk of damage to cutters, etc., but it possesses the disadvantage of a greater tendency to overleap the hard substance instead of cutting through it, and if it does this, of course, an enormous strain is put upon the cutting bar due to the inner end of the bar attempting to rise over the obstacle while the outer end of the tool remains at the level of the ordinary holing, or *vice versa*. The "Pickquick" coal-cutter is a popular type of the bar machine.

It consists essentially of five parts, namely: (1) Cutter-bar; (2) gear-head; (3) motor; (4) switch box; (5) haulage gear.

The Cutter-bar.—The cutter-bar is made of nickel steel, and is machined out of the solid. The bar is threaded spirally so as to form a kind of worm conveyor, as in ordinary twist drills, for bringing out the cuttings and clearing the cutting picks. Taper holes with "feather" ways are provided at intervals on the spiral thread, and also between the threads into which the cutter-picks are inserted.

The cutter-bar can be supplied with either right-hand thread or with left-hand thread.

The bars should be rotated only in the same direction as their threads take (looking from root to point of bar), the main idea of the threads being the clearing away of the cuttings of the tool, and if the bar is rotated in the opposite direction from the travel of the thread the worm conveyor will fail to bring out the cuttings.

Again, if an attempt is made to rotate either a right-hand threaded bar or a left-hand threaded bar in both directions there is a strong tendency, when revolving in the wrong direction,—if the holing is done in a band of hard clay, stone, or inferior coal, with a softer bed of coal above,—for the cutting-bar to rise above the level of ordinary holing, and to enter into the coal seam.

FIG. 89.—Cutter-pick.

The authors know one particular seam, somewhat of the above-mentioned section, in which it was attempted to work with a right-hand threaded bar in both directions, and the bar invariably ran up into the softer coal bed when being rotated in the wrong direction, with the result that the ordinary holding band was left adhering to the pavement, and had to be picked up by hand.

The cutter-picks (see Fig. 89) are made in two styles—single pointed and double pointed.

Referring to Fig. 90, the following is a brief description of the arrangement of the working parts of the entire machine :—

The shaft or spindle of the armature S runs in the bearings R and T.

At the gear-end of the armature shaft is the bevel pinion P, which engages with and gives motion to the crown bevel wheel M. This crown bevel wheel gives motion to the long boss O of the mitre wheel L, rotating the latter also, of course, in the process. The mitre wheel L is geared into the cutter-bar mitre wheel K, through which motion is transmitted to the cutter-bar B.

The reciprocating motion is obtained from the worm seen on the boss of the bar-driving pinion K gearing with the two small toothed wheels H, each of which drives a toggle by means of an

eccentric pin. The toggles impart a to-and-fro motion to the thrust block, with its brasses I.

This to-and-fro movement is communicated to the cutter-bar, and helps to prevent the tool from clogging or jamming in the process of undercutting.

At the other end of the armature shaft the haulage worm U gears into and actuates the haulage worm wheel W, the shaft of which runs in the bearing X, and gives motion to a ratchet and pawl arrangement which drives the haulage drum. An enlarged view of the reciprocating gear is shown in Fig. 91.

The gear-head works almost entirely under oil, ensuring copious lubrication of all the bearings.

The cutter-bar may be tilted up or down through an angle of 20 degrees by adjustment provided in the axle boxes.

The usual course in the working of a coal-cutter is to provide an open end for the machine by keeping a narrow place some little distance in advance of the working face at each end of the machine face. In the "Pickquick" machine, however, a "slewing-in" arrangement is provided in the gear-head which enables the coal-cutter to "open out an end" for itself.

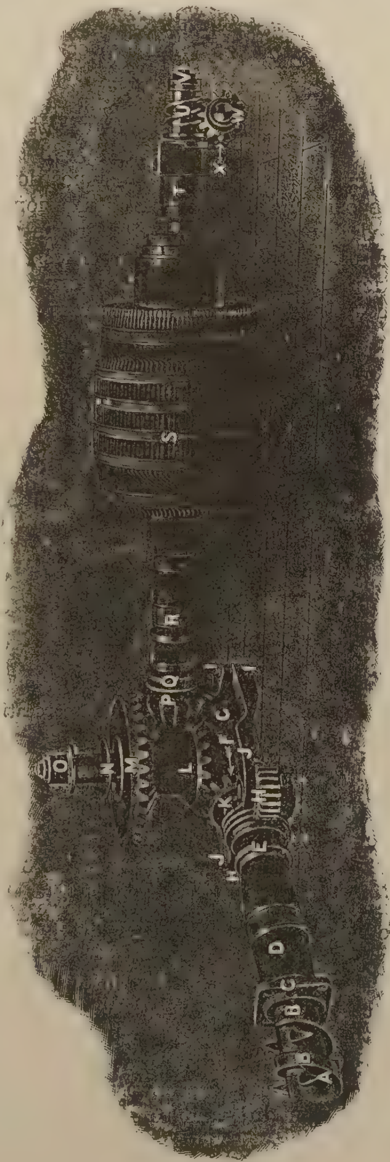


FIG. 90.—Internal view of bar machine.

The accompanying illustration (Fig. 92) shows the cutter bar being swung into position.

The Motors.—The direct current motor is of the four-pole completely enclosed type, with two compound-wound magnet coils. The armature is of the slotted drum type. The starting switch and resistance are enclosed in a flame-tight cast-iron box bolted to the end of the motor shell. The brush gear is attached to the switch box.

The diagram shown in Fig. 93 shows the connections for the direct current motor. The brush position, shown black on the diagram, corresponds to the direction of rotation indicated by the arrow when viewed from the haulage end of the machine. In order to reverse the direction of rotation, the brushes have to be moved to the dotted position. In the diagram the numerals "1–1," "2–2," etc., indicate the couplings of the coil connections within the motor. The machine

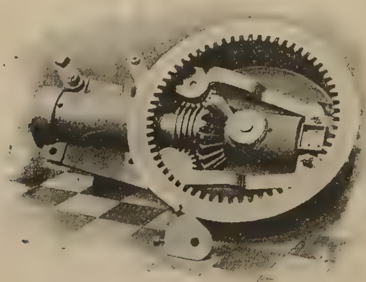


FIG. 91.—Reciprocating gear.

can also be supplied with an alternating current motor. Fig. 94 shows the bar machine at work.

THE HURD COAL-CUTTER

This machine has been in some respects re-designed, and possesses some new features awanting in the original type of bar machine, which, it is claimed, greatly increase its efficiency.

One notable feature in the new model is the introduction of a short secondary thread fixed immediately in front of the main bearing. This thread works in a shield, corresponding with the packing box of the old design, and as it rotates it presses the débris brought out by the conveyor thread away from the main bearing, protecting it entirely from dirt, and so aiding considerably in the prevention of undue heating.

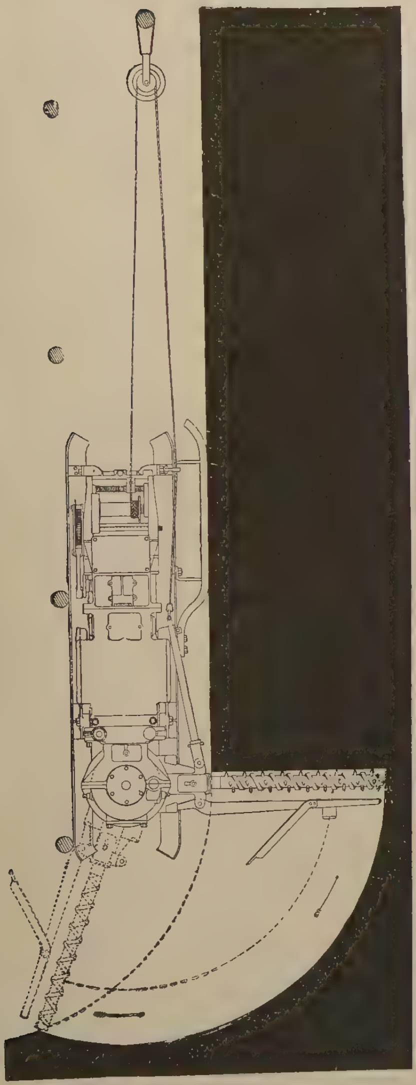


FIG. 92.—Cutter-bar being swung into position.

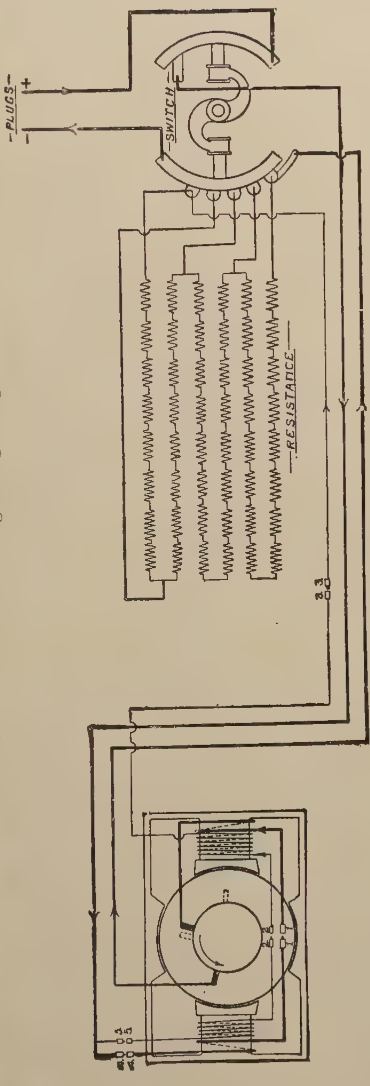


FIG. 93.—Connection for D.C. coal-cutter motor.

The cutter-bar packing gland is also done away with, and the cleaner blade broadened, a larger percentage of the cuttings being brought out of the holing in consequence.

Another improvement which is worthy of mention relates to the tilting or levelling adjustment of the cutter-bar.

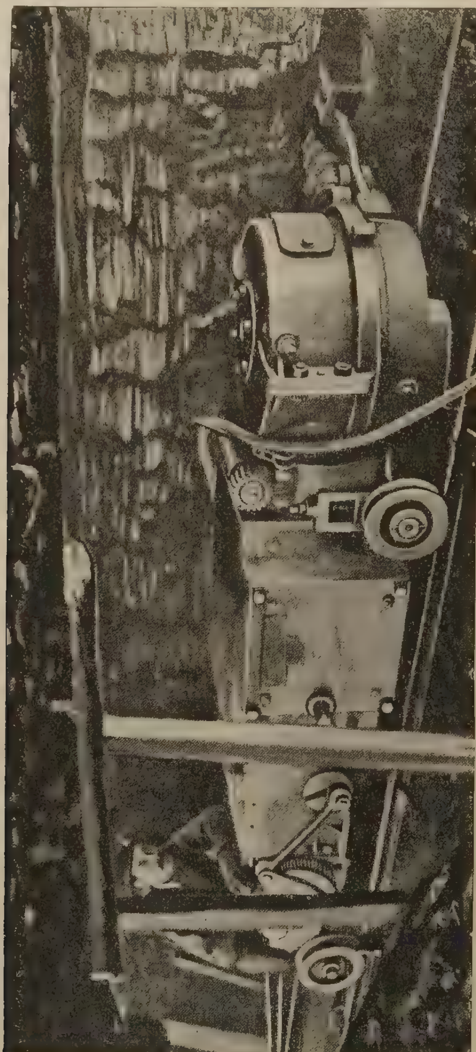


FIG. 94.—Bar machine at work.

The rear end of the machine is mounted on two screwed columns, jointed to the skids, by means of which, through side shafts workable

from both ends of the machine, the latter can be raised or lowered and the cutter-bar tilted or levelled as desired.

The machine, like nearly all modern coal-cutters, can be provided with either direct current or three-phase motors, wound for any suitable voltage or periodicity.

The dimensions of the standard three-phase machine are :—

Length over skids	8 ft. 4 in.
Width over skids	3 ft. 3 in.
Height of machine	19 in.
Depth of undercut	3 ft. 4 in. to 4 ft.
Weight of machine	26 cwts.
Power of motor	16 B.H.P.

The Disc Coal-Cutter

The disc type of coal-cutter, so far as can be judged from the number of machines in use, is the most popular type of machine in this country.

From statistics given in the Home Office Reports for the year 1905, it is found that out of a grand total of 946 coal-cutting machines in use in British mines, no less than 580 are machines of the disc type.

Some advantages possessed by the disc coal-cutter which may account for this undoubted popularity are: (1) Speed of cutting attainable, which actual working results have proved to exceed that of other types of machines in similar ground; (2) ability of cutting wheel to effectually clear away holings; (3) small height of material cut away in holing—an important advantage in thin seams where the undercutting is done in the coal.

Its disadvantages are: (1) Unsuitability for working a seam which readily falls when holed,—the falling coal would choke and perhaps seriously damage the cutting wheel and bearings; (2) the wheel bearings are underneath the coal.

The Diamond Coal-Cutter

One of the best of the disc type of coal-cutters is the machine known as the Diamond coal-cutter.

In this machine the cutting teeth are fitted into specially designed cutter-boxes, each box containing three teeth. On the disc or cutter-wheel are a number of lugs, from 10 in the 5 feet wheel to 15 in the 7 feet, and on each of these lugs a cutter-box is made to fit.

By means of the cutter-boxes the operation of changing the cutting teeth is greatly simplified and expedited. Also, when it is required to cut both ways, all that needs to be done is to turn

the boxes upside down, the teeth then facing the other way, and, of course, reverse the motor.

The revolving disc is supported by a strong steel jib bolted to the frame of the machine. The power is taken from the motor shaft through bevel gearing. The speed is then further reduced by means of spur gearing, and the outer gear wheel gears into suitable teeth on the rim of the revolving disc. (See illustration.) This arrangement may be said to be practically the same in nearly every coal-cutter of the disc type.

The speed of the disc is from 12 to 15 revolutions per minute. The machines are sometimes single motor, but they are now more often fitted with two motors—one on either side of the cutting-wheel. By the use of a pair of motors the wheel is more evenly balanced, and for a given power of machine the motors can be smaller, and, in consequence, the machine of a lower build.

The motors may be either of the series-wound continuous current type or of the polyphase type, and the B.H.P. of each motor varies from 10 to 16.

When a low voltage of, say, 200 to 220 is used the motors may be connected up in parallel, but with voltages of from 400 to 500 they are run in series.

Fig. 95 shows the standard Diamond machine, fitted with two polyphase current motors of 10 B.H.P. each. Its overall height is 19 inches; width, 3 feet 6 inches; length, 9 feet 6 inches; approximate weight, 40 cwts.; and it undercuts to a depth of 5 feet.

Anderson-Boyes Electric Coal-Cutter

This is another excellent machine of the disc type. In the standard machine a shunt-wound motor of 35 B.H.P., running at 810 revolutions per minute, is employed.

The standard machine holes to a depth of 4 feet, with a height of cut of only $3\frac{3}{4}$ inches. There are in all 20 cutter picks on the disc, 10 double-pointed and 10 single-pointed. The cutters are fitted into slots on the circumference of the disc (see Fig. 96), and held in position by means of cotter pins.

A feature of the machine is the special arrangements for adjusting the position of the brushes on the commutator. The brush rocker is operated from the outside by means of worm gearing, and two small glass windows are provided in the casing to enable adjustment to be made.

The machines may be made to run on rails, or they can be fitted with skids.

The standard size of machine is 8 feet 6 inches in length and 3 feet wide. Its total height is less than 19 inches, and its weight about 2 tons 5 cwts.

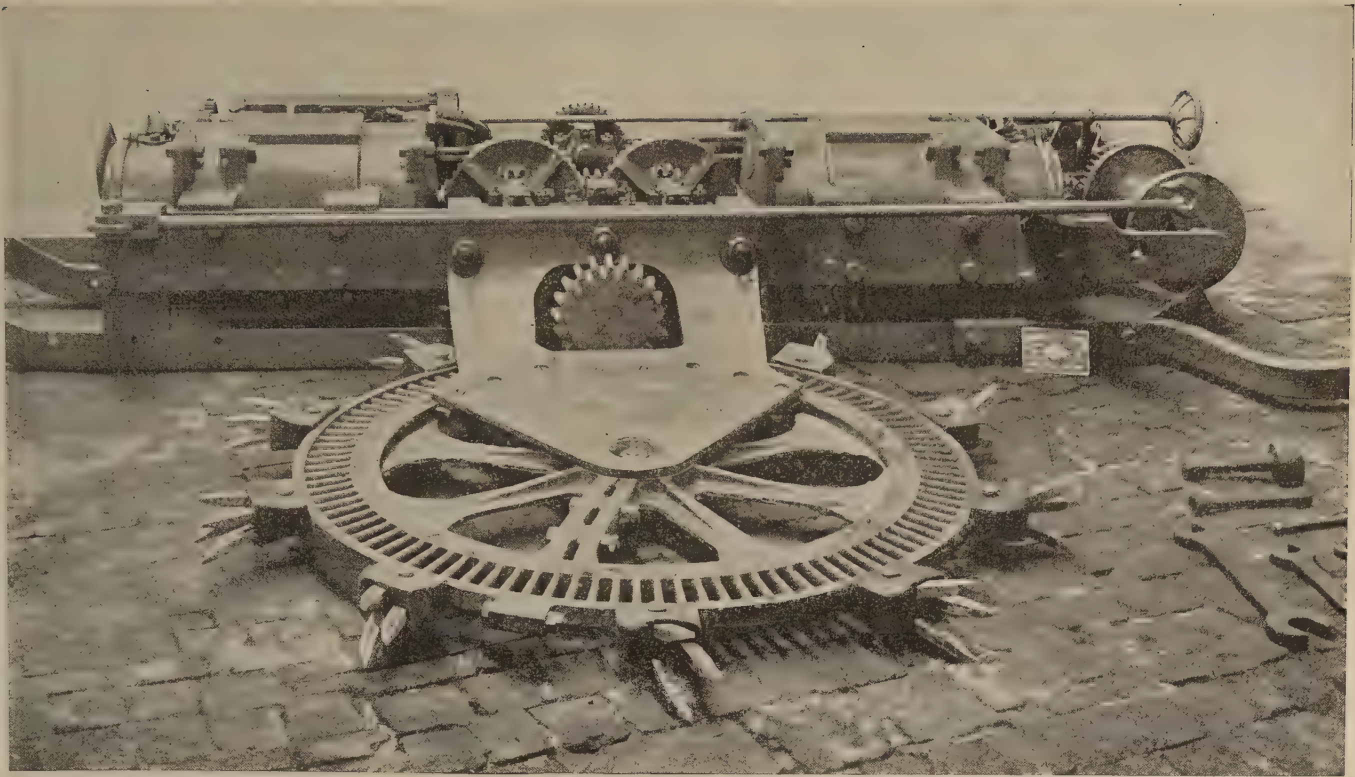


Fig. 95.—Diamond disc machine.

Fig. 96 shows the machine running on rails.

Below is given data of the work done by an Anderson-Boyes

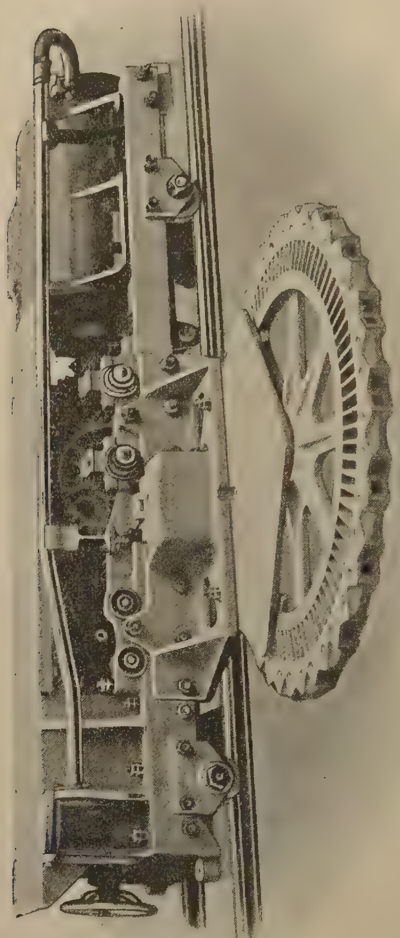


Fig. 96.—Anderson-Boyes disc machine.

coal-cutter working in an 18-inch seam in Lanarkshire. The machine cuts to a depth of about 3 feet 6 inches, and works on a face 180 yards

in length. The figures show the splendid work which this machine is capable of performing:—

Date—1907.	Yards Cut.	Hours in cutting.	Average per Hour.
March 4	125	9	13·9
,, 6	90	7	12·9
,, 7	110	8	13·8
,, 8	140	10½	13·3
,, 12	100	8	12·5
,, 13	105	10	10·5
,, 14	125	10	12·5
,, 15	80	5½	14·5
Total .	875	68	12·9

The Crescent Machine

This machine, shown in Fig. 97, is made by Messrs. A. Hirst & Sons Ltd., of Dewsbury, and its adoption has been attended with exceptional success in many instances.

The machine is built in three separate portions, and for removal from place to place can be expeditiously disconnected. The first portion of the machine contains the motor, the second the whole of the gear, and the third the haulage gear and starting switch.

The cutting-wheel is made in halves, and the cutters are fastened on to the wheel by means of the makers' improved patent cutter-boxes.

The motor is of 25 B.H.P., and is totally enclosed. The armature is of the slotted drum type, insulated throughout with best mica.

Carbon brushes are used, and these are mounted on a movable rocker-arm for ready adjustment.

The field magnets are series-wound, giving great starting torque. The reversing switch and trailer plug terminals are all inside the motor box.

The starter is fitted with a heavy D.P. barrel switch provided with magnetic blow-outs.

The cutting wheel, which is situated in the centre of the machine, is reversible, and works equally well both ways.

The standard size of the machine is 8 feet 6 inches overall length; width, 3 feet 6 inches; and height, 22 inches. Fitted specially for thin seams, the machine stands only 17 inches high.

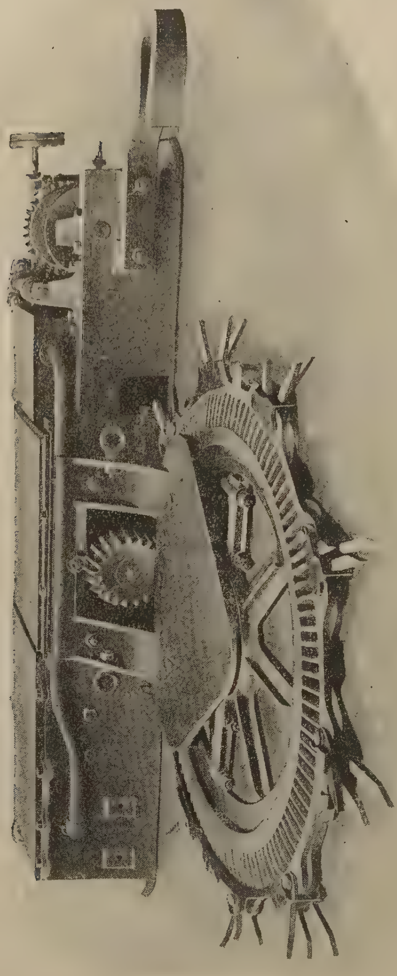


FIG. 97.—Crescent disc machine.

The machine can, however, be made of any size to suit requirements, and can be had to undercut to any depth from 4 to 6 feet.

The haulage gear is of the usual type, and the adjustable ratchet

arrangement can be set while the machine is running to any number of racks from the maximum down to nothing.

There are several Crescent coal-cutters at work at a large Yorkshire colliery, and the undernoted particulars of the performance of one of these as given by the manager of the colliery may be found instructive:—

Particulars of seam . . .	Very hard coal, with sticky top and strong spavin floor.
Thickness of coal . . .	2 feet 6 inches.
Nature of cutting . . .	Very hard and drossy coal and dirt, 6 inches thick, underneath seam.
Nature and character of roof .	Shale roof, very tender.
Nature and character of floor .	Strong spavin which soon lifts and makes a bad and uneven floor.
Inclination	About level.
Performance of machine—	
Length of face . . .	80 yards.
Depth of cut . . .	4 feet 3 inches.
Average cut per minute .	14 inches.
Actual time of cutting across face	$5\frac{1}{2}$ hours.
Number of shifts per month of four weeks . . .	20.
Distance cut per month of four weeks . . .	1,600 yards.
Output per cut . . .	90 tons.
Output per month of four weeks	1,800 tons.
Advance of face per month of four weeks . . .	$28\frac{1}{2}$ yards.
Power required	20 H.P. (maximum).
Volts	440.
Amperes	25 to 35.

The Jeffrey Disc Machine

This machine is very similar to the three already described. It is specially designed to suit thin seams, the overall dimensions being —length, 8 feet 2 inches; width, 3 feet 8 inches; height, 19 inches; and total weight, 33 cwts. The cutting wheel is made of various sizes—from 4 to 6 feet diameter being the favoured sizes.

The motor is situated in the centre of the machine, and is shunt-wound. The fast running gear works in an oil-tight casing, and copious lubrication can thus be constantly effected. The feed is obtained from an eccentric which, through a connecting rod, actuates the ratchet and pawl arrangement.

Other Disc Machines

The Clarke & Stevenson disc machine has also been successfully worked in many instances. In the latest type of this machine worm gearing has been substituted for the spur gearing originally employed. The worm gearing runs in an oil bath. It has been found that, with worm gearing, the machine makes considerably less noise when working, and also that less power is consumed.

The King coal-cutter is another machine of the disc type, made by a Leith firm. In this machine the cutters are attached to projections on the periphery of the disc by means of eyebolts. The cutters are fixed singly and are given an alternate upward and downward set, so as to make sufficient cut to clear the disc.

Electric Coal-Cutters of the Chain Type

The chain type of electric coal-cutter, although possessing several advantages peculiarly its own, cannot be said to be in very general use in British mines, and at the present moment there are only some 55 chain machines at work compared with about 150 bar machines and about 600 coal-cutters of the disc type.

In the United States, however, the chain coal-cutter is extremely popular, and is much more extensively used than either the bar or the disc type.

The chain machine can be used of a lighter make than its two rival varieties for the same class of work, and this is considered more advantageous.

The speed of cutting compares very favourably with that of the other types of machines.

Another advantage claimed for the chain machine is the low height of holing taken, but in this respect the disc machine can stand comparison with it.

The Goodman Standard Longwall Machine

Fig. 98 illustrates this type of chain coal-cutter. The machine is arranged for undercutting, and is built on a steel frame about 7 feet in length and 2 feet 8 inches wide. The frame is supported on steel shoes or skids to enable it to travel on the floor of the seam. The motor is situated about the centre of the frame. The armature shaft pinion is geared into the sprocket wheel shown in the illustration, and this wheel in turn actuates the cutter chain. The chain runs on a steel arm or jib projecting at right angles to the framework.

The machine is built to undercut to three specified depths, 38 inches, 44 inches, and 50 inches.

The cutter arm is mounted on a swinging frame, and by the simple manipulation of a lever it can be tilted up or down, as may

be required, when any hard substance is encountered in the holing. The usual feed arrangement is provided. This machine has done

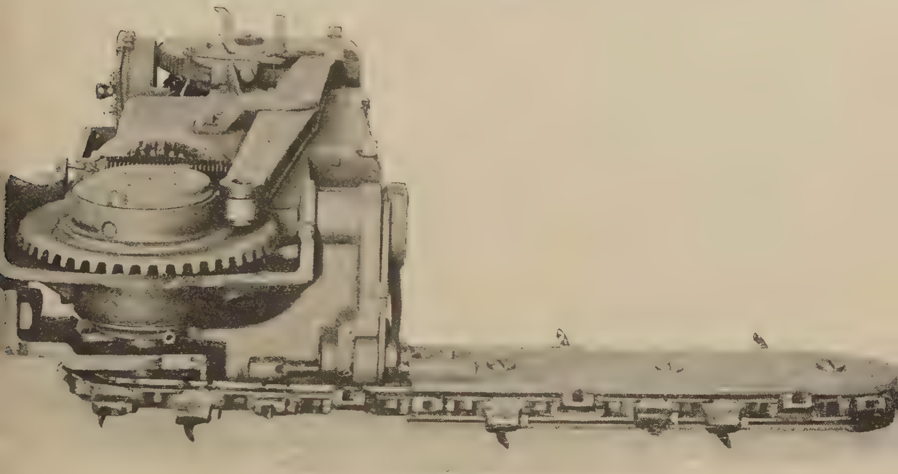


FIG. 98.—Goodman longwall chain machine.

excellent work in the United States, and also, in some instances, in this country.

JEFFREY CHAIN MACHINE

This coal-cutter is a breast machine, making its cut straight to the front, and is specially designed for pillar and stall and narrow work. See Fig. 99.

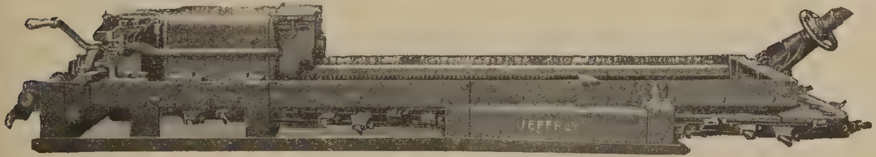


FIG. 99.—Jeffrey breast chain machine.

It consists of a bed frame which is stationary, and a sliding chain cutter frame which, as its name implies, slides inside the bed frame. The cutter chain, on which are fastened the cutting teeth, is carried on the sliding frame, and at the rear end of the latter the motor is situated.

Through spur and bevel gearing the motor drives a sprocket-wheel which actuates the chain. As the cutter chain revolves and

cuts into the coal it is kept up to its work by the slow forward movement of the sliding frame which carries the chain.

The sliding frame is worked by means of a double rack with which the spur-wheels engage, the latter being driven through worm gearing from the motor.

When the chain has reached the end of the cut the gearing is reversed by means of the reversing clutch, and the chain withdrawn. The machine is then moved sideways bodily and fixed into position for another cut, which is done alongside the previous one.

The motor is of the multipolar steel-clad type, and where necessary is totally enclosed.

The machine cuts to a depth of from 5 to 7 feet, with a width of cut of 44 inches.

The cutter-picks are held in position by means of pinching screws.

For pillar and stall and heading work the Jeffrey machine is extensively employed, and has done good service in many instances. The authors can cite one instance where the cost of driving a heading was reduced from 24s. to 13s. per yard, and the rate of travel, of course, also greatly increased.

Anderson-Boyes Longwall Chain Machine

This is another excellent machine of the chain type (Fig. 100). It has done good work in numerous instances, and under favourable conditions claims to do more rapid work than either the disc or the bar types.

For one thing, the endless chain with cutters attached forms an excellent conveyor, and sweeps out the holings very efficiently, thus enabling the cutters to work with great freedom.

The Anderson-Boyes machine is supplied with either continuous current or alternating current motors.

With continuous current motor, the machine is 16½ inches high; with alternating current motor it is 20½ inches high. Its overall length is 8 feet 8½ inches; width, 2 feet 11 inches; and cutting depth, 4 feet. It weighs about 37 cwts., and can be arranged to cut either at floor level or at any height above the floor.

The Diamond Patent Longwall Chain Machine

This machine is specially designed for undercutting in soft or friable coal.

The machine can be made to cut in both directions, the cutting tools being simple in construction and readily reversible.

The standard depth of undercut is 4 feet 6 inches; width of cut, 4½ inches; and the extreme width of jib under the coal, 18 inches.

The overall height of the machine holing at floor level is under 20 inches.

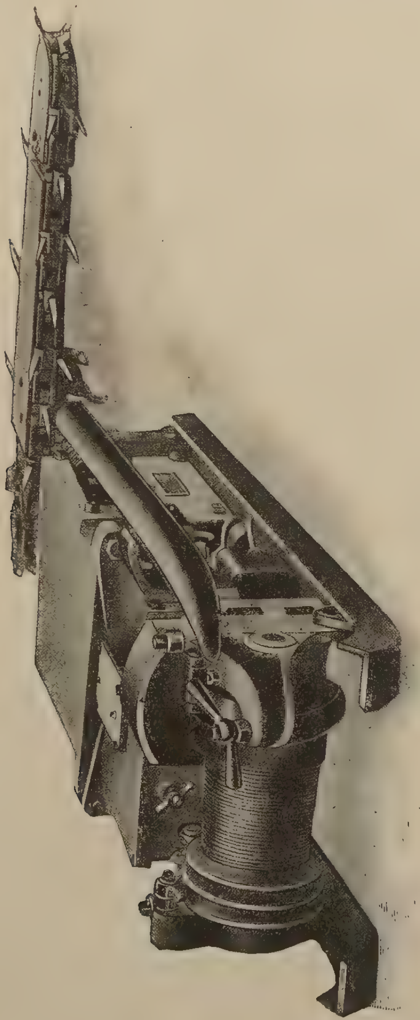


Fig. 100.—Anderson-Boyes chain machine, arranged for mid-holing.

The machine is made in two types—the one to undercut, the other to overcut. The undercut type is illustrated in Fig. 101.

The motors may be either the continuous current or polyphase

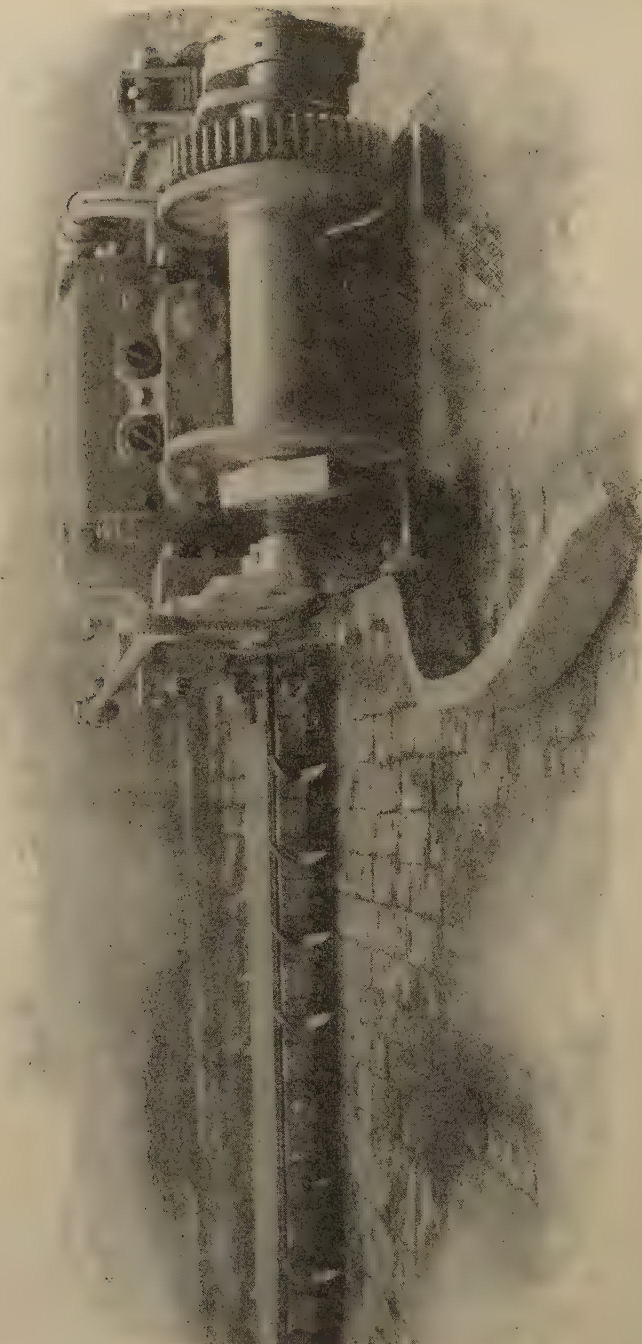


FIG. 101.—Diamond longwall chain machine.

types, and the machines can be had single or double motored as desired. The horse-power of the machine shown in the illustration is 20 B.H.P.

The Jeffrey Electric Shearing Machine

This machine is designed for shearing purposes in narrow drivages, tunnelling, and similar operations.

The machine consists of three parts—the bed frame, the sliding chain cutter frame, and the motor carriage.

The stationary frame is supported on four iron columns, which are each provided with jacks for fixing against the roof of the working. See illustration (Fig. 102).

The motor is of the four-pole type, with gramme ring armature and two field coils.

The *modus operandi* is as follows. The machine is placed in the desired position with the cutter chain close to the face of the coal, and the jacks firmly jammed against the roof.

The machine is then raised up the standards to the top of the seam, and the first cut commenced.

After the cut has been completed the machine is owered a distance equal to the cut, which may be anything from 36 inches to 48 inches deep, and the machine is then in position for a second cut. With a cut 36 inches deep, only two cuts are necessary in a 6 feet seam; and with a 42-inch cut, two cuts will suffice for a coal 7 feet thick.

The machine is said to be capable of completing a shearing 7 feet deep and 4 inches wide in a 7-feet seam of moderately hard coal in about 20 minutes, including placing in position and adjusting jacks.

Goodman Low-Type Breast Machine

This machine, like the Jeffrey header, is designed for working in pillar and stall workings and in the narrow work necessary in opening out longwall.

The machine consists of an electric motor attached to a travelling frame which carries the cutter chain, and which is actuated from the armature shaft of the motor through suitable gearing.

It is carried in a stationary steel frame, and is free to slide, in either direction, between guides. When the machine is working the stationary frame is held in position by means of the two jacks, one being at the back of the machine and the other at the front.

The cutters on the chain are so arranged that they make a kerf in the coal just sufficient to allow the travelling frame, which carries the cutter chain, to follow in the track of the cutting teeth.

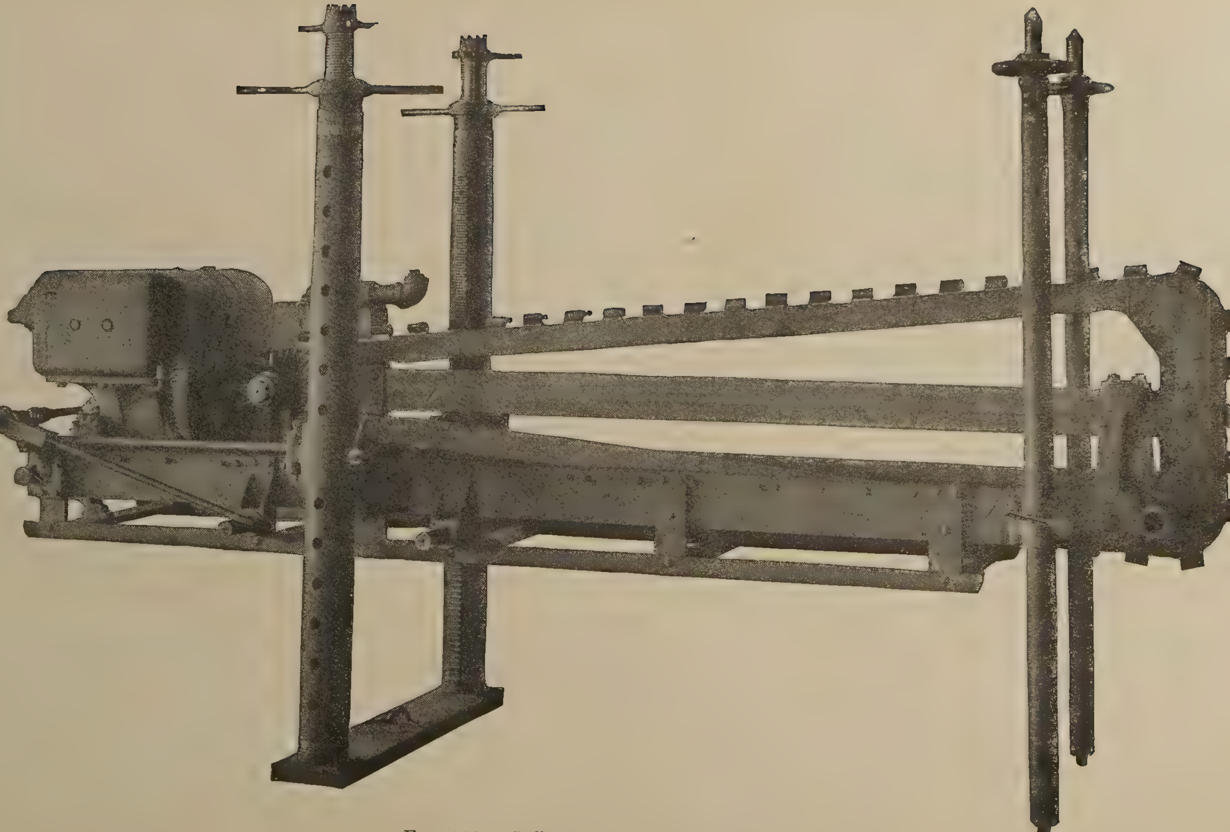


Fig. 102.—Jeffrey electric shearing machine.

In fixing the machine for a cut, the front jack is set hard against the coal face, and the rear jack is jammed against the roof. The total height of this machine is only 19 inches.

Power Truck for Chain Breast Machines

Where the chain breast machine is used for undercutting in narrow work it is necessary that the machine be often shifted from place to place. In order to facilitate the transportation of the machine from one place to another, the Goodman Company have designed a power truck which is driven by the motor of the coal-

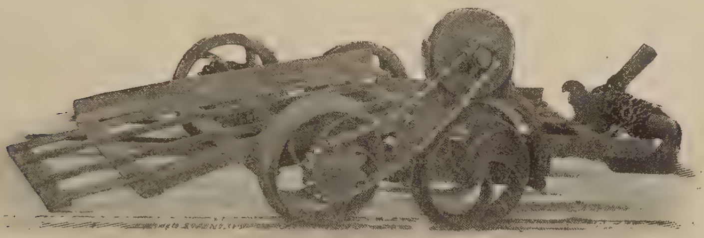


Fig. 103.—Power truck for chain breast machine.

cutter. Fig. 103 shows the power truck. It will be noticed that the power is transmitted to the wheels of the carriage by a link belt connection.

The Stanley Heading Machine

This well-known heading machine, which was originally designed to be driven by compressed air, has recently been arranged for electric driving with much success.

The machine is used principally for driving important headings, and for narrow work generally. The cutting teeth are arranged on two cutter-bars which are attached to a cross-head. This cross-head is fastened on the main shaft, which is driven through gearing from the shaft of the motor. The cutter-bars carrying the cutting teeth revolve in a circle, and carve, cut, or chip out a circular core of coal. As the cut deepens, the cutters are kept constantly hard against the face of the coal by means of a screw thread on the main shaft working in suitable gearing. The rate of advance can be regulated to suit the character of the metals being cut. The entire machine weighs between 3 and 5 tons, and the horse-power of the motor may be anything from 20 B.H.P. to 30 B.H.P., according to the size and weight of the machine.

It is said to be able to cut a circular hole in the coal, 5 feet in diameter, and about 14 feet in, in a shift of 8 hours, including shifting and setting the machine.

Power consumed by Coal-Cutting Machines

As the actual work done—plus the frictional losses—must always be equivalent to the electrical energy consumed, the power required will depend upon: (1) The hardness of the material being undercut; (2) depth of undercut and speed of cutting; (3) condition of cutters; (4) friction of gearing; and (5) losses in motor and cables.

Mr. Sam. Mavor makes the following statements:[1]—

"Considered simply as a machine, the efficiency of a coal-cutter, that is, the energy absorbed, divided by the square yards undercut, is highest when the machine is worked at full power.

"The internal losses in a coal-cutter are approximately constant for any load, and therefore the greater the load (up to the limit of full power) the less proportion of the total energy delivered to it is lost in the machine.

"One square yard undercut may be adopted as a convenient unit of work done by the machine, and the Board of Trade unit of electricity (1000 watt-hours) as the unit of energy supplied to it.

"The cost per ton of output will, of course, depend upon the cost of the energy delivered to the coal-cutter, and upon the thickness of the seam.

"At collieries where electric plant is not already installed, or where electric plant for coal-cutting cannot be associated with electrical requirements for other power purposes, it is more economical, if only a few coal-cutters are to be considered, to purchase the supply from an outside source, where this is available on moderate terms, than to instal an electric plant for coal-cutting.

"Coal-cutters, considered as power-users, must be classed as 'intermittent,' for only under favourable conditions are they in operation for more than half the cutting shift."

Mr. Mavor gives the following two examples of the cost of power supply from actual practice at collieries where electricity is purchased by meter:—

Cost of Electric Driving of Coal-Cutting Machines.

Colliery.	*A.*	*B.*
Holing material	Coaly band.	Coal.
Position of holing	16 inches above pavement.	At pavement.
Depth of cut	3 feet.	3 feet.

[1] "Practical Problems of Machine Mining," *Trans. Inst. M. E.*, 1906, vols. xxxi. and xxxii.

Colliery.	*A.*	*B.*
Thickness of coal	25 inches.	25 inches.
Distance cut per shift . . .	110 yards.	115 yards.
Lineal cutting speed, per minute .	21 inches.	14 inches.
Power exerted by motor . . .	9 brake-H.P.	13 brake-H.P.
Energy lost in cables	$2\frac{1}{2}$ per cent.	3 per cent.
Energy[1] expended per square yard cut	0·212 unit.	0·290 unit.
,, ,, ton produced .	0·330 unit.	0·450 unit.
,, ,, shift worked .	23·500 units.	33·300 units.
Rate of charge for electrical energy .	1d. per unit.	1d. per unit.
Cost of energy per square yard cut .	0·212d.	0·290d.
,, ,, ton produced . .	0·330d.	0·450d.
,, ,, shift worked . .	1s. 11·500d.	2s. 9·300d.

Where an independent generating plant for colliery use only is installed, the cost of electric driving of coal-cutters is often much higher than that shown in the above table, and if the current be used for coal-cutting alone, both installation outlay and cost of generating may be considerably less productive of ultimate profit.

Haulage Arrangements for Longwall Machines

In working a coal-cutting machine on a longwall face it is necessary that the machine be kept constantly up to its work. This is effected by means of the haulage gear, which is practically the same in every type of longwall machine. A light steel wire rope is used. The rope is attached to the haulage drum at one end; passes round a small pulley, which is attached to a prop some 30, 40, or 50 yards along the face, and, returning, is secured to the front of the machine. The haulage drum is actuated through spur gearing from a ratchet and pawl arrangement, which in turn is driven from a disc crank, operated through gearing from the motor, by means of a short connecting-rod. As the haulage drum revolves the rope is drawn in and the machine pulled steadily forward. Provision is made to enable the rate of feed to be varied from nothing up to the maximum speed.

Gate-End Panels

Gate-end panels should consist of switch box, fuse box, and plug box, each independent of the other, and all three mounted on a common frame of light construction.

Fig. 104 shows the Mavor & Coulson gate-end panel with the hinged covers thrown open.

The mains are connected to the switch box terminals, and the trailing cable attached to the plug box.

The entire apparatus is exceedingly simple and safe.

The gate-end panel should be situated in a roadway near the centre of the stretch of face worked by the machine.

[1] Including the loss of energy in cables from the surface to the face.

This arrangement enables a minimum length of trailing cable to be sufficient, without interference with the panel being necessary.

For instance, if the machine wall is 120 yards in length, and the gate-end panel is situated at the central roadway, from 65 to 70 yards of face cable will be ample for the purpose.

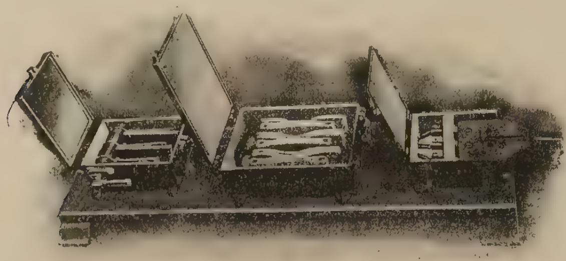


FIG. 104.—Gate-end panel.

The situation of the panel should be dry, and the panel should be protected from possible falls of coal and stone by some pieces of wood placed above and round it.

CALLENDER'S GATE-END SWITCH AND FUSE BOX

A gate-end box to be satisfactory must possess the following essential characteristics: (1) Easy connection and disconnection of the main cable, (2) efficient and satisfactory switch and fuse gear, and (3) facilities for the ready connection and exchange of the trailing cable.

Callender's gate-end box satisfactorily fulfils these requirements.

In this apparatus the main cable is brought into the right-hand side of the box, and the three cores connected by patent couplings to three copper rods which connect through glands to the fuse terminals in the main chamber. This chamber contains the switch and fuse—the switch being operated by a removable handle, and so arranged that, if a fuse blows, it is impossible to renew it with the switch in the "on" position.

Further, by means of the interlocking gear shown in the illustration (Fig. 105), it is impossible to remove the lid of the chamber before opening the switch. The main chamber, when the connections are made, is filled up with resin oil, which prevents flashing when a fuse blows.

So efficient and complete are the safety arrangements of the apparatus that not even the trailing end, which is provided for the ready attachment of the trailing cable, can be removed or connected up until the switch is in the "off" position.

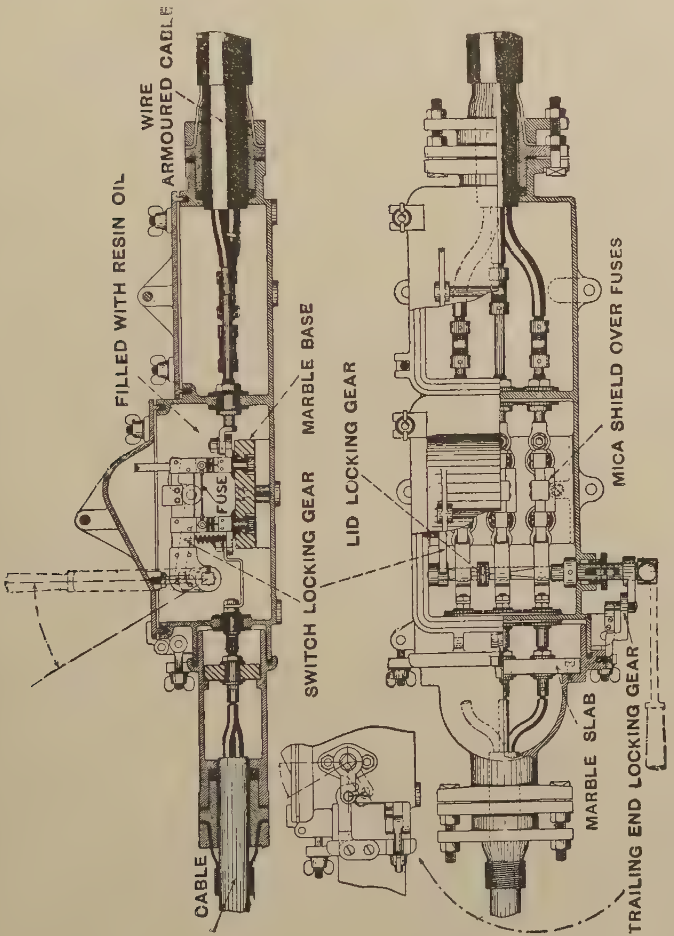


FIG. 105.—Callender's gate-end switch and fuse box.

In no case, therefore, is it possible that a spark should occur as the result of negligence or ignorance. The apparatus is therefore very suitable for use in fiery situations.

The Trailing Cable

These cables may be of the three-core, two-core, or "C.C." concentric types, according to the form of current supplied to the machine. They should be well and heavily insulated, and perfectly flexible.

In some cases the insulation is protected by an outer covering of extra stout braiding, but more commonly the protection takes the form of a flexible spiral steel armouring.

The steel or wire armouring stands the rough usage to which a face cable is unavoidably subjected much better than does the braid covering, but there is the added danger of the armouring cutting into the insulation and causing a short circuit.

The person in charge of the machine, as may be learned from Rule 7, Section V., of the Special Rules for the Installation and Use of Electricity, must not allow the trailing cable to be dragged along by the machine, but should always see to it that a yard or two of slack cable is kept immediately behind the advancing coal-cutter.

The machineman must also examine the trailing cables at least once in every shift, and if any defects or abrasions are noticed he should have them promptly repaired.

Care and Management of Coal-Cutting Machines

When a new machine is to be started for the first time all the bearings should be thoroughly soaked with good cylinder oil some time before starting. All the gear wheels and other moving parts should be well rubbed over with a plentiful supply of Stauffer lubricating grease.

When the machine has been put into proper working order, about half a gallon of oil per shift will be sufficient additional lubricant to add to the bearings, and about 1 lb. of Stauffer grease will suffice for the gearing.

In revolving bar machines, the gland outside the cutter-bar bearing should be removed, and the space behind it filled with Stauffer.

This should be done at the beginning of each cutting shift, and during the shift, if the bearing tends to heat.

On starting the machine, care should be taken to start slowly, pausing on each of the switch contacts to give the machine time to gain in speed.

After the machine has been started, and allowed to run light for a minute or two, the feed gear may be thrown in, and cutting commenced. This also should be done gradually, that is to say, the minimum rate of travel should first be given the machine, and the feed gradually increased till the maximum is reached.

Before switching "off," the feed should be released, and the cutting tool allowed to run for a sufficient time to thoroughly clear itself, and take the strain off the haulage rope.

Observance of this precaution will save trouble when re-starting, and avoid undue stress on the motor and "blowing" of fuses. With three-phase machines this is especially important.

The machine should never be started until the cutting tool is in position ready for a cut.

Messrs. Mavor & Coulson Ltd., makers of the "Pickquick" coal-cutter, issue the following hints to drivers. Although intended for drivers of bar machines, these recommendations may well apply to any type of machine.

1. Never start the machine till the bar is in the cut or close against the face.

2. Never step or lean over any portion of the bar while it is rotating. (Careless workmen are sometimes apt to do this, to clear the cutter of coal or stone, and it is certainly a most dangerous practice.)

3. It is of vital importance that the cutters be kept in good order.

4. Never drive the machine when the working parts are loose or noisy; have the necessary adjustments made.

5. If the machine while working begins to make any unusual sound, or to vibrate unduly, ease the feed, or stop until you have ascertained the cause.

6. Keep joints of inspection doors in good order.

7. Frequently examine and tighten, when necessary, every bolt and nut.

In addition to the above, the regulations laid down in the Special Rules for the Installation and Use of Electricity (Section V.) should be memorised by every driver or other coal-cutter attendant. We would recommend that all managers of collieries where electrical coal-cutting machines are at work should have the foregoing hints to drivers, together with Section V. of the Special Rules, printed out, and a copy given to each coal-cutter attendant.

Such a course, if accompanied by strict discipline, would tend to the more efficient and safe working of the machine.

A copy of all the Special Rules ought also to be in the hands of every attendant of electrical coal-cutting machines.

Coal-Cutter Motors

The direct-current type of motor is most generally in use for coal-cutting machines, although the three-phase motor has in some instances been adopted with much success, and seems in many respects to be superior to the direct-current motor.

The three-phase type is probably more suitable in fiery situations, but as both types require to be totally enclosed where accumulations of fire-damp are to be feared, the advantage is of little importance. The voltage used varies from 400 to 650, the latter potential being the maximum allowable in a coal-cutter motor.

The type of motor to be used in a coal-cutting machine is, naturally, determined by the form of current to be used, and if the generating plant is already installed there is practically no other course open than to adopt one suited to the current generated, unless provision is made for converting the current between the generator and the motor.

Starting switches for coal-cutter motors are of the ordinary metallic resistance type, provision generally being made so that a slight pause *must* be made at each of the contact studs. An auto-starter is sometimes used in polyphase machines.

The Cost of Coal-Cutting Machines varies from about £250 for a machine of light make and small power to about £450 for a machine heavy in build, excellent in design, and of large cutting capacity.

CHAPTER VIII

ELECTRIC HAULAGE, WINDING, AND LOCOMOTIVES

Advantages of electric over steam haulage—Systems of electric haulage—Endless rope haulage—Main-and-tail rope haulage—Comparison of power required in endless rope and main-and-tail haulages—Single rope haulage—Endless chain haulage—Portable haulage gears—Motor-driven creeper belts—Liquid starting switches for haulage motors—Polyphase haulage plants—Electric winding—Comparison between steam and electric winding—Systems of electric winding—Westinghouse converter-equaliser system—The Ilgner system—The Siemens-Ilgner system—Peebles-Ilgner system—Tests of electrical winding plant—Estimate of the cost of electric winding plant—Electrical locomotives, advantages and disadvantages—Trolley system—Rack rail system—Goodman gathering locomotive—The Jeffrey type—Mather & Platt underground type.

Electric Haulage

Electricity as the motive power for driving the different forms of haulage plant which form so important a part of the fittings of a colliery has of late years come rapidly into favour.

There is divided opinion as to whether it is superior to the steam-engine for such work, and many engineers are still in favour of transmitting the power from a steam-engine on the surface down the shaft by means of band-ropes to the haulage drums.

Unquestionably, however, there are many advantages which can be claimed for motor-driven haulages, and the following are some of these :—

1. Band ropes are very expensive in first cost, having to be of the very best material, and are very costly to maintain, their life seldom averaging more than about two years. Considerable space is required in the shaft for the ropes, guide-pulleys, etc. All this is unnecessary where the haulages are motor-driven.

2. The motor-driven haulage is certainly superior to the steam-driven haulage with the steam-engine underground. The atmosphere in the vicinity of steam-engine rooms underground is necessarily raised to an uncomfortable temperature, and an outburst of steam in an underground steam-engine house would certainly be a source of extreme danger. The intermittent working of some hauling engines, such as those operating single rope or main-and-tail rope haulages, is

also against the economy and efficiency of steam-driven haulage, whereas intermittency of working has no such effect on motor-driven haulage plants.

Against these advantages in favour of motor-driven haulage, there are the usual objections to the use of motors for all forms of underground work, such as necessity for belting or gearing, danger from fire or shock, etc.

The forms of underground or surface haulage which are suited to the adoption of motors are :—

1. Endless rope haulage.
2. Main-and-tail rope haulage.
3. Single rope haulage.
4. Endless chain haulage.

Endless rope haulage is one of the best, if not the best, method of haulage applicable to mines, and is suitable for long distance transportation of large outputs.

The rope may be above or below the tubs, or it may be at the side, and the tubs may be put on the ropes singly at intervals, or in trains of two or more by means of clips which firmly grip the rope. The speed of the rope is usually from 2 to 3 miles per hour, and this low speed of course necessitates a considerable reduction in the speed of the motor. The reduction is generally accomplished by means of spur gearing.

Generally the load in endless rope haulage is fairly uniform, but sometimes, where branches are being worked, a portion of the rope occasionally runs "empty" or without load.

To suit a varying load, the shunt-wound motor is the best, as this type gives practically constant speed for all loads.

Fig. 106 illustrates a three-drum endless rope haulage gear with driving motor of 100 H.P. Each drum is fitted with friction clutch and brake, and each can be separately thrown in or out of gear at will.

As may be seen from the illustration, the speed of the motor is firstly reduced by means of spur gearing, and latterly by helical gearing.

The plant is built by Messrs. Clarke, Chapman & Co., and is at present doing good work at an important colliery.

Horse-Power of Motor required for Endless Rope Haulage

In calculating the horse-power of motor required for endless rope haulage, many factors must be taken into consideration, as, for example, speed of rope, weight of tubs when empty, total weight of coal carried, and number of tubs on the rope at one time, friction of rope, rollers, tubs, wheels, etc., gradient of road, etc.

The accompanying table gives the horse-power of motor required per 100 yards of double road for various gradients and outputs per hour.

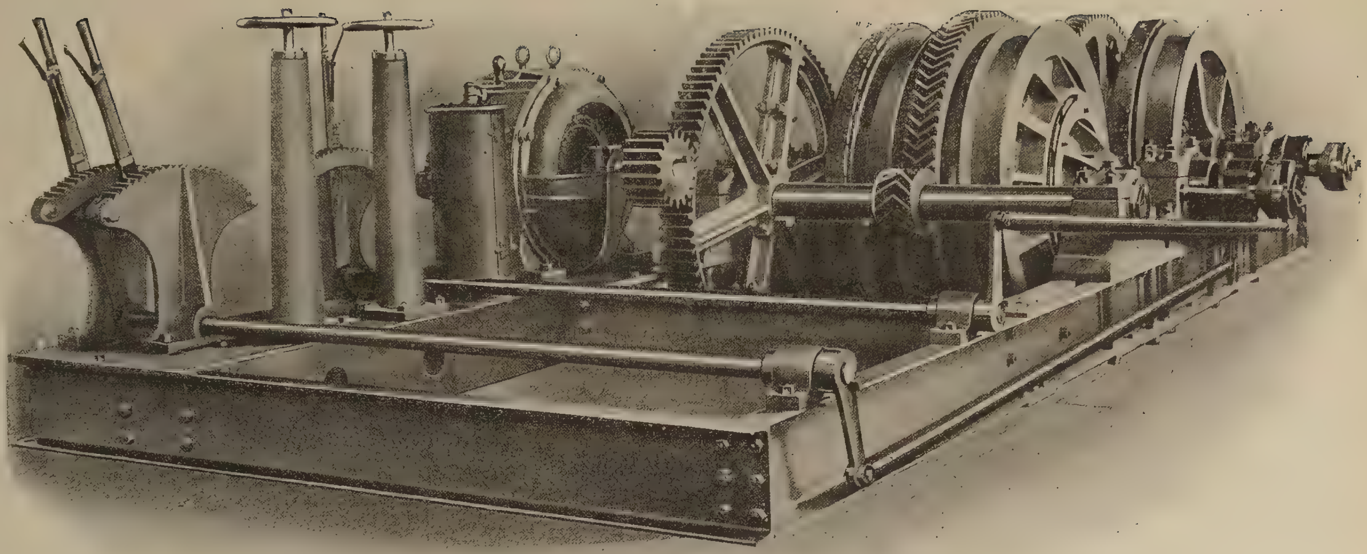


FIG. 106.—100 H.P. three-drum endless rope haulage gear.

The table assumes that the empty tubs going down the gradient help to balance the full tubs coming up, and that the weight of the tubs is 40 per cent. of the coal they carry. The speed of rope assumed is $2\frac{1}{2}$ miles per hour, which is a fairly high average for endless rope haulage.

TABLE SHOWING HORSE-POWER OF MOTOR REQUIRED FOR DIFFERENT GRADIENTS AND OUTPUTS (CLARKE CHAPMAN).

Output of Coal in Tons per Hour.	Gradient in Inches per Yard.						
	Level.	1 Inch.	2 Inches.	3 Inches.	4 Inches.	5 Inches.	6 Inches.
30 tons	0·945	1·35	1·75	2·16	2·56	2·97	3·37
40 ,,	1·1	1·64	2·18	2·71	3·25	3·79	4·33
50 ,,	1·26	1·93	2·6	3·28	3·95	4·62	5·29
60 ,,	1·41	2·22	3·03	3·83	4·64	5·45	6·26
70 ,,	1·57	2·51	3·45	4·4	5·34	6·28	7·22
80 ,,	1·72	2·8	3·88	4·95	6·03	7·11	8·19
90 ,,	1·88	3·09	4·3	5·52	6·73	7·94	9·15
100 ,,	2·04	3·39	4·74	6·08	7·43	8·78	10·13
150 ,,	2·81	4·83	6·85	8·87	10·9	12·9	14·9
200 ,,	3·59	6·29	8·99	11·7	14·4	17·1	19·8
250 ,,	4·37	7·73	11·1	14·5	17·8	21·2	24·5
300 ,,	5·15	9·19	13·2	17·3	21·3	25·4	29·4

Where the road is of greater length than 100 yards, and the same output per hour is required, the horse-power in each instance in the foregoing table must be multiplied by the total length of the road divided by 100, because the horse-power varies in direct proportion to the length of the road.

For example, suppose the length of the road to be 1000 yards, with a gradient of 2 inches to the yard, and an output of 50 tons per hour.

Referring to the above table we find that for a road 100 yards long with a gradient of 2 inches per yard and an output of 50 tons per hour, the necessary horse-power of motor is 2·6 H.P.

For a road 1000 yards long, the H.P. of motor required will be—

$$\frac{2{\cdot}6 \times 1000}{100} = \underline{26 \text{ H.P.}}$$

Fig. 107 shows the endless rope haulage room at a South Wales Colliery. The plant was built by Messrs. Ernest Scott & Mountain Ltd., Newcastle.

The motor is of 75 B.H.P., and develops from 50 to 70 H.P. according to the load put on the rope.

The first reduction is made by rope drive from a pulley on armature shaft of motor, cotton ropes being used for the purpose. The second reduction is made through helical gearing (see illustration).

The cotton rope drive is found to be very efficient and reliable, and may well be advocated for driving haulage gears wherever the necessary space is available. Some advantages which may be claimed for the cotton rope drive in haulage gears are the following:—

1. The rope forms an elastic medium between the motor and the haulage gear, and relieves the motor of sudden strains or shock.

2. In the event of any excessive load coming upon the motor the ropes will slip.

3. The freedom from vibration on the motor shaft, particularly in

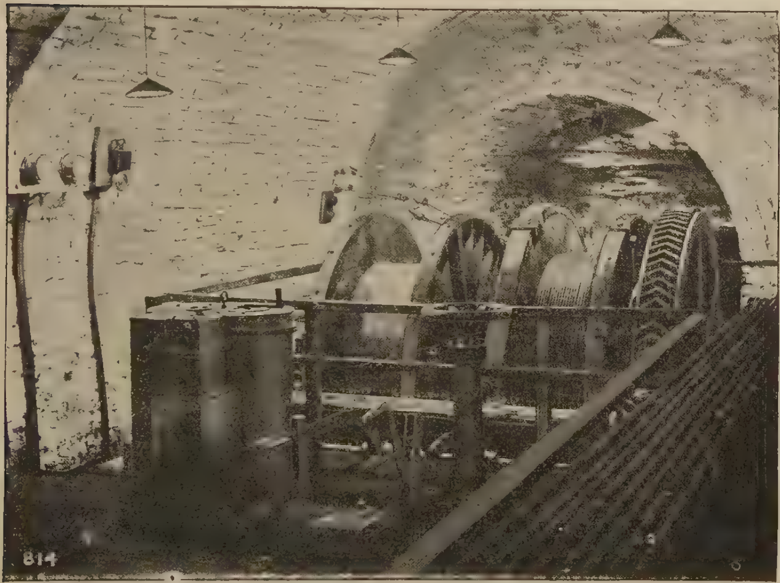


Fig. 107.—Endless rope haulage room.

continuous current motors, reduces the risk of breakdown to a minimum, and with three-phase motors it also avoids the risk of the rotor running in contact with the stator due to the heavy wear upon the bearings arising from gearing.

4. Generally the life of the machinery is greatly increased.

Main-and-Tail Rope Haulage

This system of haulage is very suitable for varying gradients. Two drums are required, one for the main rope which pulls the full tubs outbye, and the other for the tail rope which pulls the empty train inbye.

Both drums are fitted with clutches, generally of the cone friction type, so that they can be thrown in and out of gear when required.

The tubs are run in sets or trains of any number from two upwards, there being, in the case of large outputs, sometimes as many as from 20 to 30 tubs in a single train. In consequence of this, the strain on the rope is very great, there being no empty train to counterbalance the weight of the full set, and motors of a very high horse-power are often necessary on this system.

Fig. 108 shows a main-and-tail rope haulage plant driven by a 215 H.P. electric motor.

The drums are fitted with a special type of improved cone friction clutch, and the brakes may be operated either by a foot lever or by a hand wheel and screw.

As the speed of the rope in main-and-tail haulage is frequently as high as 12 miles per hour, the necessary reduction of the motor speed is much less than in endless rope haulage.

Horse-Power of Motor required in Main-and-Tail Rope Haulage

In calculating the horse-power of motor required on this system, instead of taking the average gradient, as in endless rope haulage, the heaviest gradient on the road must be taken, as there is no counterbalancing load in main-and-tail haulage. The friction of the tail rope must also be taken into consideration in calculating the total work done by the motor in pulling the full load uphill. The accompanying table gives the horse-power of motor required for various gradients and weights of sets.

Table showing Horse-Power of Motor for Various Gradients and Loads (Clarke Chapman).

Weight of Set in Tons.	Gradient in Inches per Yard.						
	Level.	1 Inch.	2 Inches.	3 Inches.	4 Inches.	5 Inches.	6 Inches.
7	23·8	37	50·4	63·7	77	90·4	103·6
10	27·4	46·4	65	84	103	122	141
15	33·5	62	90	119	147	176	204
20	39·6	78	115	153	191	229	267
25	45·7	93	141	188	235	283	330
30	51·8	109	166	222	279	336	393
40	64	140	216	292	367	443	519
50	76·2	171	266	361	455	550	645
60	88	202	316	430	544	658	772

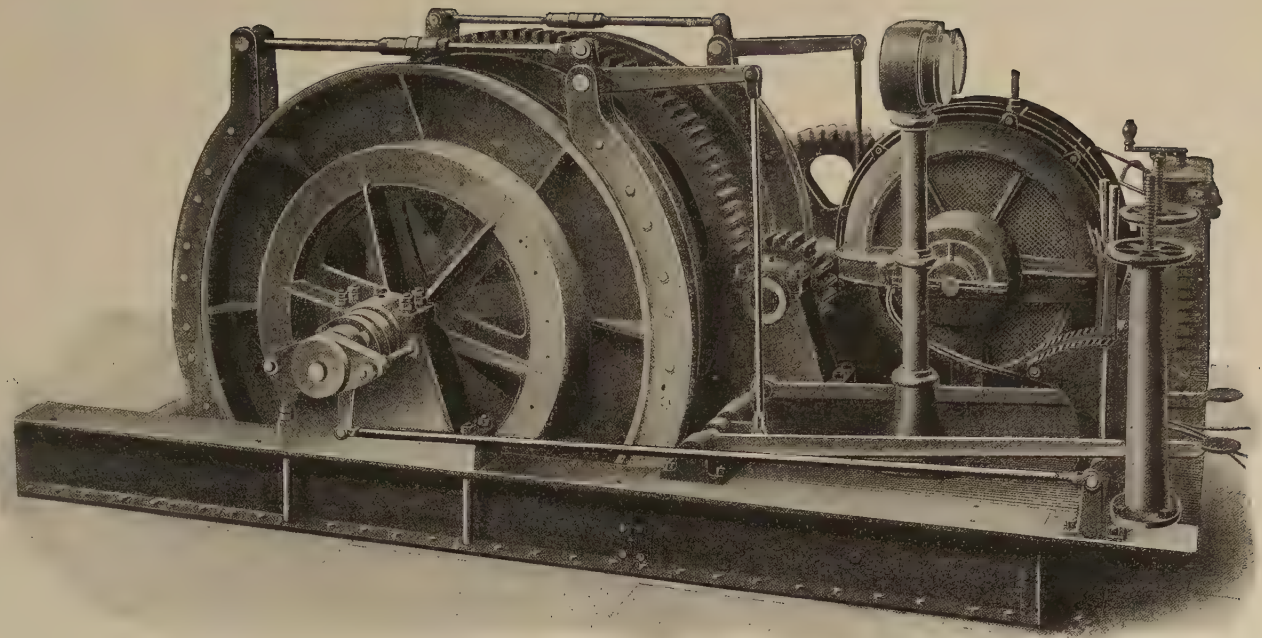


Fig. 108.—215 H.P. main-and-tail haulage gear.

The speed of rope taken is 8 miles per hour, and the length of run 1000 yards.

In the above table we have assumed :—

Rolling friction—40 lbs. per ton.
Pull due to rollers, etc.—0·25 lbs. per yard.
Efficiency of haulage gear—70 per cent.

For speed of 10 miles per hour the horse-power may be increased in proportion.

Comparison of the Power required for Main-and-Tail and Endless Rope Haulages

The endless rope system of haulage is much more economical as regards the horse-power of motor required than the main-and-tail rope haulage system, as a brief reference to the tables already given may readily show.

The following example is given to illustrate more forcibly the contrast :—

Work to be done—	
Output in day of 10 hours . . .	500 tons.
,, per hour	50 ,,
,, per minute . . .	17 cwts. (approx.).
Length of road	1760 yards.
Gradient against load . . .	5 ins. to the yard.
Weight of each empty tub . . .	4 cwts.
Weight of coal per tub . . .	10 cwts.

For the above output, length of road, etc. a motor of about 85 H.P. would be ample to perform the work if the system of haulage were the endless rope, whereas, if the main-and-tail rope system were employed, it would require a motor of at least 270 H.P. to do the work.

The saving both in first cost and in consumpt of power to be obtained by the employment of the endless rope system where practicable is thus considerable.

Single Rope Haulage

This system of haulage is suitable for gradients of from 1 in 18 upwards. It is the simplest system of all, as only one rope and one rope drum are necessary. The full train is drawn up as the rope is being coiled on the drum, and the empty train runs back by gravity, uncoiling the rope off the drum in the process.

In calculating the power necessary in single rope haulage, the weight of the full train, the weight of the rope, the speed of the tubs, and the friction, are the factors which have to be taken into consideration; there is no compensating balance as in endless rope, where the weight of the empties helps to balance the full train.

To show how the horse-power of motor necessary may be arrived at, the following example is given:—

Suppose we have a full train of ten tubs, each carrying 10 cwts. of coal, and the weight of each empty tram 5 cwts., the maximum speed of the rope 12 miles per hour, and the steel wire rope weighing 8 lbs. per fathom; the road being 600 yards long, and of an average gradient of 3 inches to the yard. Then the total pull on the rope will equal—

$$10 \times (10+5) \times 112 = 16{,}800 \text{ lbs. weight of coal and tubs.}$$
$$8 \times 300 = \underline{2{,}400} \text{ ,, weight of rope.}$$
$$\text{Total, } 19{,}200 \text{ lbs.}$$

$$\text{and } \frac{19{,}200}{12} = 1600 \text{ lbs. dead weight to be lifted.}$$

And for friction allow—

$$\frac{19{,}200}{30} = \underline{640 \text{ lbs.}}$$

Then total load = 2240 lbs.

Then foot-lbs. to be done per minute at a speed of 12 miles per hour—

$$\frac{2240 \times 12 \times 5280}{60} = 2{,}365{,}440 \text{ foot-lbs.}$$

$$\text{And H.P.} = \frac{2{,}365{,}440}{33{,}000} = 71{\cdot}6 \text{ H.P.}$$

This represents the useful work done, but allowance must be made for the friction of the gearing, etc., and for efficient working the motor should be 50 per cent. stronger than the above.

Therefore actual H.P. of motor required equals—

$$71{\cdot}6 + 50 \text{ per cent.} = 107{\cdot}4 \text{ H.P.} \quad \textit{Ans.}$$

Say, a motor of 110 B.H.P.

Endless Chain Haulage

Motors have also been applied to the operation of endless chain haulage systems with satisfactory results.

The system is not so efficient, however, as the endless rope haulage, although there are a few advantages to which it can lay claim.

The weight of the chain to be kept in motion by the motor is, of course, a distinct disadvantage. The principal advantages are the slow speed, with the consequent small amount of wear and tear entailed in chain, hutches, pulleys, etc., and the facility with which branches can be worked and curves negotiated.

In endless chain haulage plants special attachments have to be employed on the haulage drum in order to prevent the chain

from slipping. The general arrangement is to have a number of studs screwed into the drum shell. The links of the chain catch into these studs, and therefore a suitable grip is obtained.

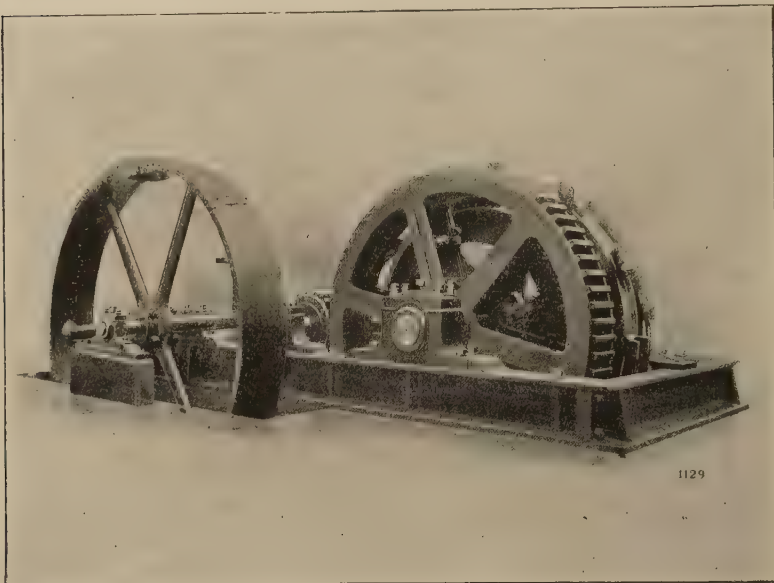


FIG. 109.—Endless chain haulage gear.

Another method is shown in Fig. 109, curved clips being adopted instead of the studs.

PORTABLE HAULAGE GEARS

Light haulage gears, which can be easily transported underground to wherever required, are now coming greatly into favour, especially for inbye work.

The old system of bringing the coal from the working face to the main haulages by means of ponies and horses, although admirable in many respects, is certainly expensive compared with the efficiently worked mechanical haulage, and, besides being cheaper in the end, a larger output is often the outcome of the adoption of motor-driven haulage gears for such work.

Fig. 110 shows a portable electric haulage gear for the endless rope system, built by Messrs. Ernest Scott & Mountain Ltd., which possesses the advantage of being small and compact and easily

fitted up. The horizontal rope wheel is driven through worm gearing from the armature shaft, and the motor as illustrated is

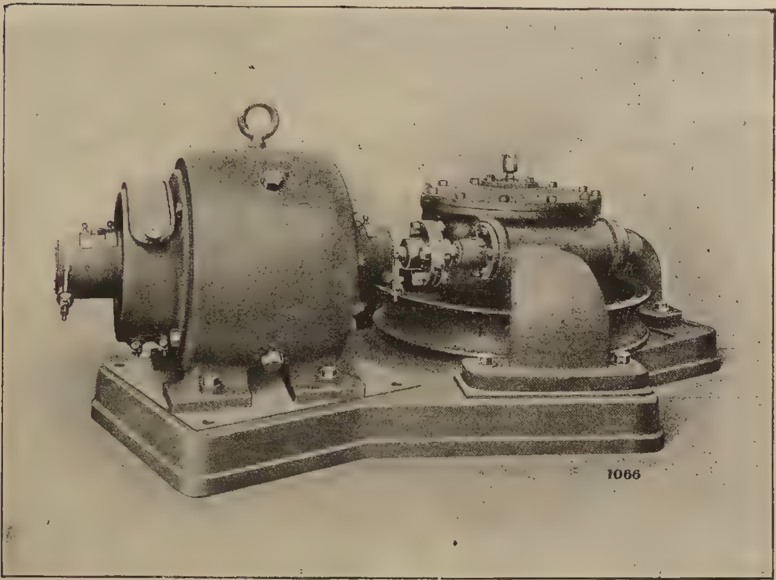


Fig. 110.—Electric haulage gear, working through worm gearing.

of 5 B.H.P. The gear is generally mounted on a bogie, so that it can be more easily moved from place to place.

Motor-Driven Creeper Belts

Creeper belts may be suitably driven by means of electric motors, and as the power necessary for such purposes is generally of small dimensions, the motors can be situated so as to take up very little room, and be entirely out of the way. As an example of the usefulness and the class of work undertaken by the motor-driven creeper belt system, the plant at the Prestonlinks Colliery, Prestonpans, may be cited.

The system is at work at the shaft bottom, and is employed to haul away the empty tubs from the back of the winding compartments past the side of the shaft to the loading platform, the loads being all put on the cage from the front, while the empties are received at the rear. From the loading platform the empties gravitate into the several sidings reserved for the different

haulages, the guide switches being operated so as to allow the tubs to run into whichever siding where they may at the moment be required. A 5 H.P. 4-pole shunt-wound motor drives the creeper, and develops about 3 H.P. with a regular supply of hutches.

Starting Switches for Haulage Motors

For the gradual starting up of haulage motors, liquid resistances are preferable to metallic, being more gradual in their action. In the ordinary open type of liquid starter, however, there are one or two undesirable features—evaporation, accumulation of dust and dirt on the surface of the liquid, and so forth—which have tended to injure the popularity of the liquid starting resistance in mining operations, and enhance the value of the metallic resistance and switch.

The enclosed liquid starting switch patented by Woolliscroft has, however, removed the troublesome features that are characteristic of the open knife switch.

In Woolliscroft's liquid switch, the fluid resistance, which is a solution of soda and water, is contained, together with the entire switch mechanism and connections, in a cast-iron box or case. This cast-iron case is mounted on insulated bearings, and is free to rotate when picked up by the catch actuated by the retaining coil in series with the field. In Fig. 111 is shown a diagram of the switch mechanism and connections. In the diagram, A is the lever which is held by the retaining catch G when in the vertical position indicated by the dotted lines. The retaining catch is operated by the coil E, which is in series with the field. The catch G retains the lever A in its vertical position only during such time as the current keeps above a certain minimum amperage. When the amperage falls to this minimum the coil E loses its magnetism, releases the retaining catch, and allows the lever to "switch off."

In the illustration the switch is shown with the circuit open, and ready for starting a shunt motor.

A maximum release is also provided at D in the diagram. H is a short circuit contact fixed to the casing B, and C a sliding contact fixed to the internal switch blade.

This sliding contact rotates with B, but is insulated from it.

The level of the liquid in the casing is indicated by the dotted line F.

Some of the advantages claimed for the Woolliscroft switch are the following :—

1. Practically no attention is required.
2. No time limit required for starting up.
3. Little or no evaporation.
4. Absolute freedom from sparking.

By altering the density of the soda and water solution the Woolliscroft resistance can be made to suit voltages up to 700 volts.

The cost of a Woolliscroft patent enclosed liquid starting switch varies from £12 for a motor of 40 B.H.P., and with both "overload" and "no voltage" release, to £30 for a motor of 130 B.H.P. with the same safeguards. Enclosed liquid reversing and controlling switches on the same principle as the starting

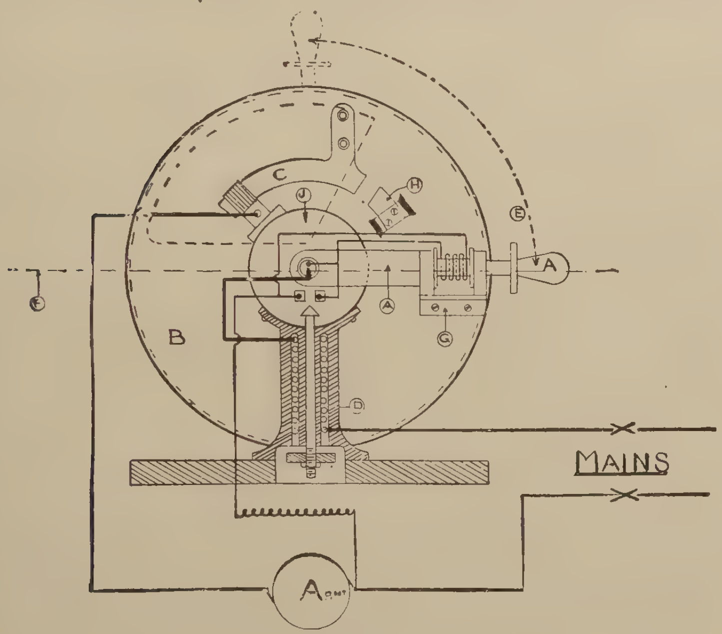


Fig. 111.—Woolliscroft starting switch.

switch already described are also on the market. These switches are made by the Sandycroft Foundry Co., Chester, and other firms.

Polyphase Haulage Plants

Polyphase motors are now being very widely adopted for operating haulage gears. As an example of these up-to-date plants, the installation at Clifton Colliery, near Nottingham, is worthy of mention. The current is three-phase, and the working voltage is 2500 volts, with a periodicity of 25 cycles per second. There are two haulage gears, both endless rope, at work, one operated

by a three-phase motor of 125 B.H.P. and the other by a motor of 60 B.H.P.

In both gears the first-speed reduction is made by means of a rope drive, and the speed is then further reduced by means of spur gearing.

Electrical Winding

The operation of winding plant by means of electric motors is one of the most important developments in the ever-spreading application of electricity to mining.

True it is, the systems of electric winding at present in actual use still leave much to be desired in the way of simplicity, economy, and suitability to the exacting conditions inseparable from colliery winding, but, nevertheless, the best of these have proved sufficiently successful, and possess certain important advantages over even the most approved class of steam winding engines, to deserve the thoughtful consideration of mining engineers who have been or may soon be entrusted with the installation of new and important colliery winding plants.

It is a well known fact that colliery winding engines are notoriously wasteful of power, and no mining engineer worthy of the name would for a moment think of upholding the steam-driven winding engine from the standpoint of economy.

This great waste of power is, of course, due entirely to the intermittent nature of the work with which the colliery winding engine has to deal.

An engine whose work it is to start a mass of machinery from rest, and keep it in motion at a constant uniform speed for hours on end, may be said to be working under practically ideal conditions, and can be fitted with all the steam-saving accessaries indispensable in a modern first-class steam-engine.

The winding engine, however, has a totally different class of work to undertake.

It has to start from rest a mass of machinery amounting to anything from 60 to 100 tons, or even more, and in a very few seconds impart a velocity of 30, 40, or even 50 miles per hour, only to throw to the winds, by the application of the brakes, every unit of the vast amount of energy which has been stored up in the moving parts of the machinery and the cages ere the completion of the wind. This is the one great and altogether deplorable feature in colliery winding by means of the steam-engine. The vast amount of steam consumed in the starting of the machinery and in the attainment of the necessary speed is altogether out of proportion to the useful work done in raising the load.

From the above remarks it is evident that electric winding, to prove its superiority over the steam-engine, must show itself less

wasteful of steam than the latter, and consequently it is in this direction, that is, economy in steam consumpt, that the efforts of advocates of electric colliery winding have been principally directed.

One very serious objection to the employment of electric winding gears is the delicate nature of the apparatus as compared with the robust and sturdy build of the steam winder. If a steam winding engine breaks down, it is generally possible for the ordinary colliery engineer to put the matter right in a very short time. When an electric winding plant gets out of order, however, it requires an expert electrician to find out the cause of trouble, and perform the necessary repairs. Generally speaking, it cannot be denied that the steam winder will withstand rough handling with greater freedom from serious injury than can the electric winding engine.

Systems of Electric Winding

There are at least half a dozen systems of winding at present being exploited by as many firms, each claiming to be superior to any other so far as efficiency, economy in steam consumpt, and ease of control are concerned. The three systems best known in this country, however, and those which in actual working have proved themselves to be the most deserving of attention, are (1) the Westinghouse converter-equaliser system, (2) the Siemens-Ilgner system, and (3) the Peebles-Ilgner system.

The Westinghouse Converter-Equaliser System [1]

In this system either direct current or induction motors may be employed to do the actual winding, suitable provision being made to enable this to be done.

As shown in Fig. 112, the general arrangement of the system consists of a rotary converter (1) connected through transformers (2) to the high-tension transmission lines. On its direct current side the rotary converter is connected to a direct current machine (3) acting sometimes as a generator and sometimes as a motor, and fitted with a flywheel (4). The rotary converter (1) is compounded in a special way so as to supply automatically the magnetising currents required for the induction motors on the system. The voltage of the direct current flywheel machine (3) is controlled automatically by a quick-acting regulating apparatus (5), which is actuated from the high-tension transmission line through series transformers. This whole arrangement constitutes the Westinghouse converter-equaliser, the action of which is to discharge energy into the high-tension line system whenever the load on the latter is greater than the constant output; and to store up energy in the flywheel

[1] *Electrical Magazine*, March 1907.

whenever the power demand in the high-tension supply system is less than the constant output of the station.

When there is no load on the high-tension system the rotary converter (1) runs with approximately 100 per cent. power factor, and gives up to the flywheel—through the medium of the direct current machine acting as a motor—energy corresponding to the constant output of the station, until the maximum speed is reached. The flywheel is of sufficient capacity to take care of the overload and underload periods.

The flywheel machine (3) is preferably built for high speeds in order to obtain high electrical efficiency with light weight, and may have a maximum slip of 40 per cent. of its maximum speed, though in ordinary service 30 per cent. slip is sufficient.

When direct current winding motors are employed the arrangements are as follows:—

The rotary converter is connected to the alternating current mains in the same way as in Fig. 112, the direct current side being joined up to a direct current machine fixed on the same shaft as the direct current regulating machine. The latter is electrically connected in series with the direct current machine, and acts as a voltage-regulator, by means of which a variation of voltage at the winding motor terminals between minus maximum and plus maximum is obtained.

The direct current voltage of the machines is one-half of the maximum voltage of the winding motor, so that, if the latter is designed for 500 volts, the voltage of the former will be 250 volts.

When the winding motor has to be started, the voltage of the regulating machine will be equal and opposite to that of the direct current machine. By decreasing gradually the voltage of the machine to zero, and increasing it in the reverse direction, any desired pressure between zero and maximum may be applied to the winding motor.

The diagrammatic sketch (Fig. 113) shows the electrical and mechanical control-gear used in conjunction with the Westinghouse converter-equaliser system when applied to a winding engine driven by a polyphase motor. The drum or friction-wheel brakes are normally actuated by the compressed-air cylinder B; or, in case of emergency, by means of a weighted lever C. The whole control gear is operated by means of three levers *a*, *b*, and *c*, which are fixed on the driver's platform. The lever *a* on the right-hand side of the driver actuates the main reversing switch D and the liquid starting rheostat E. The lever *a* can be moved either forwards or backwards from its central or off position—the position of D and the direction of rotation of the winding motor depending on this. When the lever *a* is moved, the main switch D is actuated first, the movement of the liquid starter E being secondary, beginning only after D has reached a definite position. If the lever is moved into an intermediate position at a moment's notice, it acts as follows: It releases

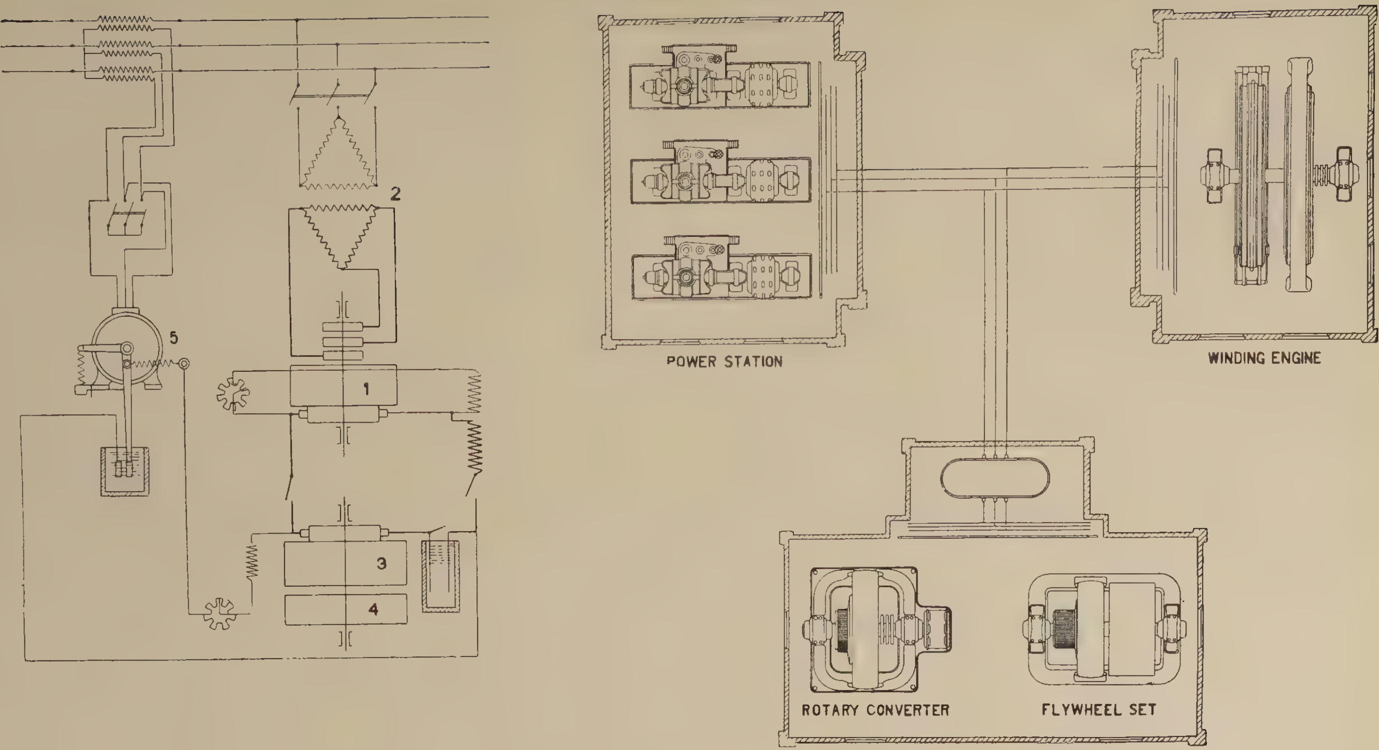


Fig. 112.—Diagram showing the Westinghouse converter-equaliser system of winding.

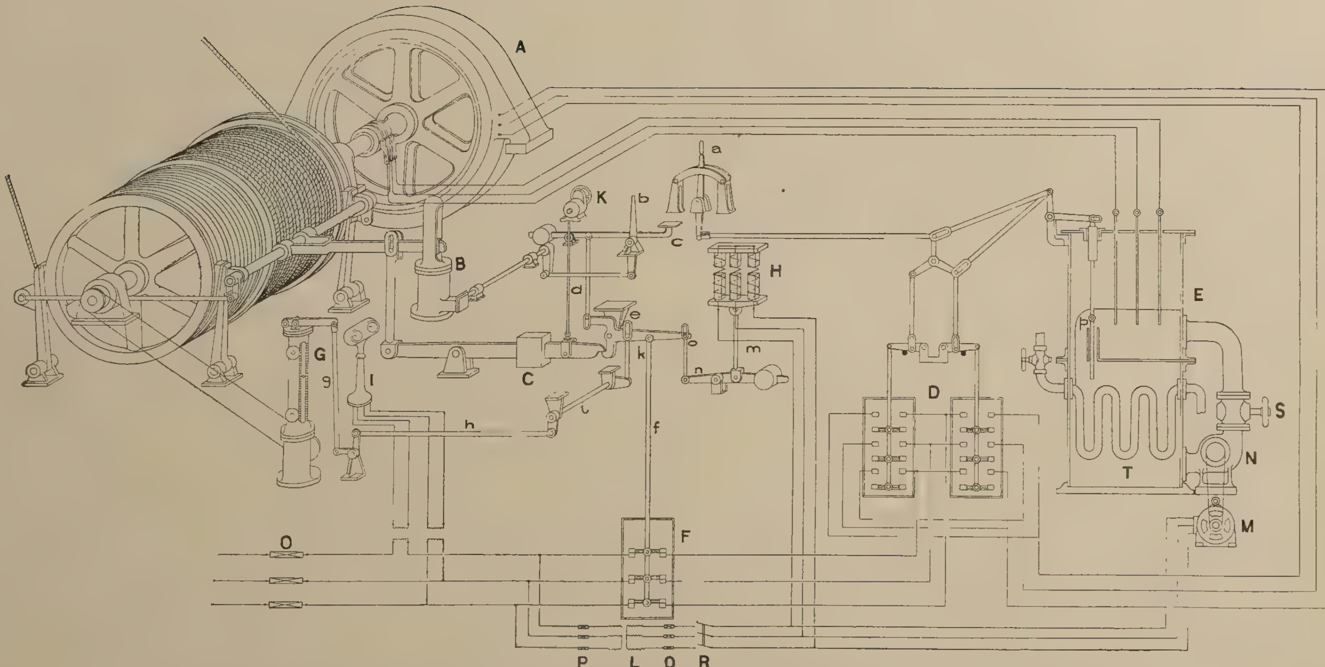


FIG. 113.—Diagram showing control of Westinghouse electric winding gear with three-phase winding motor.

the weighted brake lever C, which is normally held up by the mechanism *d* and *e*; it opens the emergency switch F by means of the rods and links *d*, *e*, and *f*, thus cutting off the supply of current to the motor. The drum will also be stopped automatically in the event of overwinding or a failure of the electricity supply. The provision for this is as follows. The tripping mechanism of the emergency brake lever is connected mechanically to the depth-indicator G by means of rods and links *g*, *h*, *i*, *k*, and *e*, and the emergency brake lever C will be released at the end of the travel in case of overwinding, the emergency switch F being operated at the same time through the extra link *f*; an abnormal fall of voltage or failure of the supply will cause the solenoid cores H to drop, and the emergency brake to be released through the link motions *m*, *n*, *o*, and *e*; the emergency switch being also thrown off through *m*, *n*, *o*, *e*, and *f*. The replacement of the weighted brake lever C is effected by means of a winch K. The reversing switch is operated as before, namely, to its full final position, whereas the liquid starter is only moved to a position corresponding with that of the operating-lever handle. In this manner the speed of the winding engine can be varied within wide limits. The action of the liquid starter is such that the acceleration is automatic, and quite independent of the speed with which the lever *a* is operated. Should, however, the handle *a* be moved so slowly that the amount of water supplied to the upper tank of E exceeds its holding capacity, the acceleration will be less than the normal. The design of the control gear is such that the electrical braking of the motor when lowering may be arranged for if necessary. The lever *b* fixed on the left-hand side of the driver operates the pneumatic brake through B. The foot lever *c*, which is between the two others, is only operated by the driver in cases of emergency, when it is required to stop the winding drum.

The Ilgner System

This system of electric winding has been employed in German and other continental mines for a number of years, and has in many instances proved very successful. The system is a combination of the three-phase and continuous current systems, three-phase current being got from the generator and converted to continuous current by means of a converter set, for use in a continuous current motor on the main winding gear.

Later developments in the Ilgner system have resulted in the introduction of two modifications, namely, the Siemens-Ilgner system and the Peebles-Ilgner system. Both of those systems have been applied to the operation of colliery winding plants, in this country as well as on the Continent, with good results.

The Siemens-Ilgner System

This system has been very largely adopted on the Continent. There are also two plants working in this country, one at the Rhondda Colliery, South Wales, and the other at the Axwell Park Colliery, Durham. Both plants use three-phase alternating current. For much of the following information the authors are indebted to Messrs. Siemens Bros., London.

Fig. 114 illustrates diagrammatically the general features of the Siemens-Ilgner system. From the mains of an electric power station current is drawn for driving a motor-generator (converter) consisting of a motor coupled to a dynamo. This converter transforms the supply current into direct current at variable voltage, and this is used for driving the winding motor. Either a continuous or three-phase supply is suitable for driving the motor-generator. The advantage of a three-phase supply at high voltage is that long transmission lines can be used, involving neither great first cost nor heavy losses in transmission, the load on the line being very uniform, and not exceeding, as explained later on, the average demand of the winding engine. With a supply of this kind the high-tension current is led through a connection box *a* to the converter motor, which is started by means of the switch *c*.

The converter motor is built to suit the character of the supply, whether direct or three-phase current. It can also be arranged for a single-phase supply, such as may exist in some outlying districts. The converter is provided with a heavy flywheel, in the form of a single steel casting or forging, which is capable of running with safety at a high circumferential velocity.

The energy which is stored in the flywheel is drawn upon for taking up the fluctuations in load of the winding engine, and equalising the demand upon the power station. The converter generator and the winding motor are both of the direct current type. They are separately excited, and when the supply is single or three-phase the exciting current is obtained from a small direct-coupled dynamo.

When the main supply is direct current the general arrangement of the plant is the same as for alternating current, except that the converter motor is of the direct current type and the exciter is omitted, the exciting current being taken direct from the supply mains. The armatures of the converter generator and winding motor are connected in series. A set of regulating apparatus is provided by which the exciting current of the converter generator is varied at will from zero to a positive or negative maximum. The degree of excitation determines the voltage generated and applied to the terminals of the winding motor armature, and the revolutions of the latter vary approximately in direct proportion. The winding motor

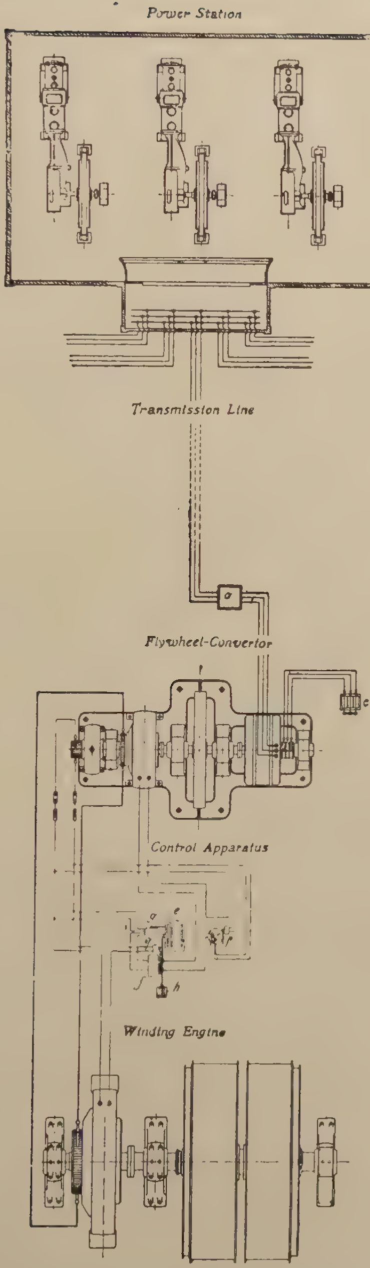


FIG. 114.—Diagram showing arrangement of Siemens-Ilgner system.

may either be coupled direct to the drum, as shown in Fig. 114, or arranged to drive the drum through single reduction spur gearing.

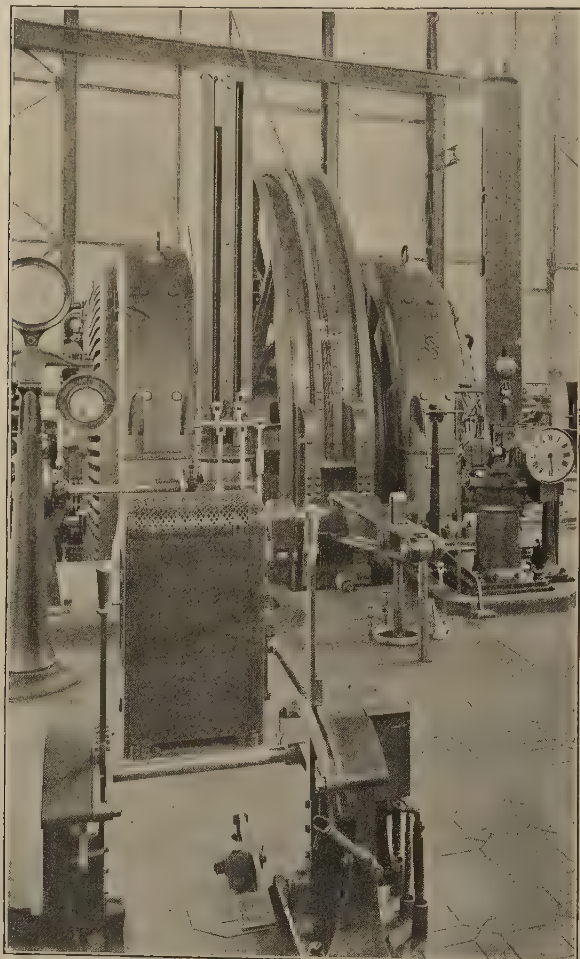


FIG. 115.—Siemens-Ilgner winding engine, with Koepe pulley.

The former arrangement has advantages in simplicity of construction and freedom from noise in working, and is usually the most practical for plants of larger sizes. For smaller plants, however, it is

more costly than the geared arrangement. In very large plants two coupled motors, one on either side of the winding drum, are sometimes used (see Fig. 115). This arrangement is chiefly advantageous in giving extra security against breakdown, since in an emergency one motor can be used to wind at half-speed. The control gear for the winding motor and drums is operated through two hand levers (Fig. 115).

The one at the right hand of the operator actuates the control gear for the winding motor, and by means of the other the brakes are applied. The two levers are interlocked, so that when the machine is put in motion the brakes are released, and when the current is cut off they are again automatically applied. The control gear consists of an ordinary field rheostat, and by its use the winding drums may be started at "creeping" speed and rapidly and uniformly accelerated until the maximum winding speed has been attained, and then rapidly, yet gradually, "slowed down" at the completion of the wind.

The movements of the winding drums may be in either direction according to the position of the control lever. The lever, when in the "off" position, is in the centre of the guide frame, and, by pushing the lever from him, the driver sets the cages off in one direction, while, by drawing the lever towards him, the direction of motion of the cages is reversed. An automatic safety brake for the prevention of overwinding is also provided. The power for the automatic brake is got from a small electrically driven air-compressor, a receiver of sufficient storage capacity being included so as to maintain power enough on all occasions. The compressor is automatically stopped or started when the air pressure in the receiver rises or falls between given limits.

An indicator, driven by gearing from the main winding shaft, is also provided to show the position of the cages in the shaft.

Electric Winding Plant at Axwell Park Colliery

An electric winding plant has recently been installed at the Axwell Park Colliery, Durham.

The system of winding adopted is the Siemens-Ilgner, as above described.

The shaft is $252\frac{1}{2}$ feet deep.

The time taken to wind is about 40 seconds. Of this period about 12 seconds are taken up for acceleration, that is, for getting up speed, then follows 23 seconds of full speed run, and then 5 seconds for retardation or slowing down.

At full speed the cage travels about 8 feet per second.

The power for operating the plant is obtained at 550 volts, 40 cycles from the Axwell Park Sub-Station, which is situated some 1000 yards from the pit mouth.

The Sub-Station is fed with three-phase current at 5500 volts from the Carville Power Station of the Newcastle-on-Tyne Electricity Supply Company Ltd., some 9 miles distant, and from the Priestman Power Station, about 5 miles away, both working in parallel.

The Peebles-Ilgner System

In the Peebles-Ilgner system a continuous current dynamo, electrically driven, supplies power to a continuous current motor which either directly or through spur gearing actuates the winding drums. The converter set consists of a motor which takes the current from the power mains, and, on the same shaft, the dynamo giving out continuous current for the driving of the winding motor. Fixed intermediately between the motor and the dynamo in the converter set is the heavy flywheel common to all flywheel storage systems. In the Peebles-Ilgner system, methods of controlling and regulating the winding gear are adopted somewhat similar to those employed in the Siemens-Ilgner system.

An electric winding gear on the Peebles-Ilgner system has been in operation for some time at the works of the Tarbrax Oil Company Ltd., Tarbrax, Scotland. The plant, as described by Mr. James Caldwell,[1] consists of the flywheel motor-generator described above and a continuous current winding motor. Alternating three-phase current is obtained from mains coming overhead from the power station at the works, and actuates the induction motor in the motor-generator or compensating set. This induction motor develops 80 B.H.P., and runs at a speed of 730 revolutions per minute.

The generator is a continuous current machine of the same capacity as the induction motor; but it is so designed that it can stand very heavy overloads, such as are constantly occurring in the process of winding.

The winding motor is coupled direct to the drums. It is kept constantly excited by a three-phase induction motor of 10 B.H.P.

The horse-power of the winding motor is 200, and it runs at a speed of 57 revolutions per minute. Its speed is regulated by a controller operated by a hand lever. The winding drums, of which there are two, are each 8 feet in diameter and 2 feet wide.

The winding ropes are $1\frac{1}{16}$ inch in diameter. The plant is designed for an output of 640 tons in 8 hours from a depth of 420 feet. The full load is 25 cwts. per wind. The whole journey is completed in 25 seconds, the speed being 23 feet per second.

The time allowed for decking is 30 seconds per trip.

The flywheel in the motor-generator set is $6\frac{1}{2}$ feet in diameter, and weighs 6 tons.

The following results were obtained in a test of the Tarbrax

[1] *Trans. Inst. M. E.*, 1906, vol. xxix. p. 221.

electric winding plant made with a view to ascertaining the efficiency of the plant under working conditions:—

TEST OF TARBRAX ELECTRIC WINDING PLANT.[1]

Time.	Wattmeter Readings.	Power Consumption.	Time.	No. of Winds.	Power Consumption. Per Minute.	Power Consumption. Per Wind.	Average No. of Winds per Minute.
A.M.	Units.	Units.	Minutes.		Units.	Units.	
10·40	00907·0	...	...	...	...	...	...
11·00¼	00916·6	9·6	20¼	20	0·474	0·480	0·987
11·20	00924·9	8·3	19¾	15	0·420	0·554	0·759
11·40	00936·4	11·5	20	19	0·575	0·605	0·950
12·00	00944·1	7·7	20	14	0·385	0·549	0·700
P.M.							
12·20	00953·9	9·8	20	18	0·490	0·545	0·900
12·43	00961·8	7·9	23	15	0·343	0·526	0·655
1·00	00970·4	8·6	17	16	0·506	0·537	0·941
Totals and averages		63·4	140	117	0·455	0·541	0·840

During each wind about 12½ cwts. of shale were raised.

The above results show that throughout the test the average power consumption was 0·541 unit per wind; and allowing 12½ cwts. for each wind, this shows a power consumption of 0·866 unit per ton of shale raised during the test.

RHEOSTATIC CONTROL SYSTEM

In some instances winding motors can be driven advantageously direct from the supply mains, an ordinary rheostatic control being used.

In such cases it is necessary to vary the resistance in series with the armature or rotor by very small increments, so as to obtain a gradual and uniform speed control. A liquid resistance is frequently used for this purpose, both because of its large heat capacity and the simplicity and ease with which it enables such a uniform regulation to be obtained. The resistance is either cut in and out by gradually lowering specially shaped plates, by means of the control lever, into the liquid; or a small circulating pump is provided which raises the surface of the liquid so as to gradually cover the area of the contact plates. Such a plant would be less costly than one arranged on the more complicated systems, and although far from being economical as compared with these, it may be used with

[1] *Trans. Inst. M. E.*, 1907, vol. xxxii. p. 287.

advantage, particularly in the case of isolated plants of small size, and where economy in power consumption is not of so great importance. The rheostatic control system is designed by Messrs. Siemens Brothers Ltd.

Cost of an Electrical Winding Plant

The question as to the advisability of installing an electric rather than a steam winder does not admit of a general answer, but depends upon the conditions to be met with in each individual case. If we consider the cost of the winding engine alone, the electric engine is usually more expensive than the steam-engine. If, however, account be taken of the extra boiler plant which it is necessary to have with the steam winder, on account of its lower efficiency, then it is usually found that the electrical installation will involve little, if any, greater capital expenditure than that required for a steam plant (Siemens).

The following estimate is given by Mr. George Ness[1] for a plant of similar power to the Tarbrax winder, and will serve as a guide to the outlay involved in the erection of an electric winding engine, together with the cost of working :—

Estimated Cost of an Electrical Winding Plant.

Generators (including stand-by set), switchboard, buildings, boilers, brickwork, chimney, and cabling . . .		£8,500
One-third of this amount is charged against the winding plant .		£2,833
Winding plant, foundations, and buildings . . .		2,800
Total capital charges		£5,633
Depreciation and interest on capital, £5633 at 10 per cent. per annum		£563
Do., per week of 11 shifts of 8 hours each . . .		£10, 16s. 6½d.
Do., per shift of 8 hours		19s. 8·2d.
Do., taking rated output of 640 tons in 8 hours .	. per ton	0·368d.
Oil and waste, including power station charges, per week	£0 15 0	
Wages of winders	3 0 0	
Proportion of power station wages chargeable against winding . . per week	1 0 0	
Total . . ,,	£4 15 0	
Do.	. per ton	0·260d.
Coal, 4 pounds per unit, at 6s. 8d. per ton .	. ,,	0·140d.
Total cost per ton of shale raised .	. ,,	0·768d.

[1] *Trans. Inst. M. E.*, 1907, vol. xxxii. p. 287.

Electric Locomotives

Electric locomotives for underground haulage purposes have many advantages over stationary haulage plants.

The most important of these are: (1) Greater suitability for working "inbye"—that is, the removal of "fulls" and supplying of empties at the working face, and for traction work to and from the main haulages. In this capacity the electric locomotive takes the place of mule and manual haulage, and for this class of work is undoubtedly superior. (2) Greater adaptability for the working of branch roads communicating with the main engine plane. (3) Ropes, etc. are dispensed with, representing a considerable saving.

In this country electric mine locomotives have, up to the present, been little adopted, but in America and on the Continent they are in extensive use, some hundreds of locomotives being at present at work in the States alone.

As one striking instance of the successful adoption of locomotive traction in Britain, the installation at the Duddingston Mine, Winchburgh, near Edinburgh, may be cited:—

The system is the ordinary trolley arrangement, and the line extends from the mouth of the mine to the retorts some two miles distant.

The locomotives are worked by two continuous current motors, each 30 H.P., arranged in series. They are capable of dealing with 26 waggons, each carrying 26 cwts. of shale, in a single train.

The locomotives are capable of developing a speed up to 30 miles an hour.

The power is obtained from the Winchburgh Power Station. It is there generated at 3300 volts three-phase, and then converted, through a rotary-converter, to direct current at 500 volts for the trolley system. The plant has been working for several years, and has given every satisfaction.

There are certain drawbacks which undoubtedly retard the development of locomotive mine traction in this country as well as others, and the following are some of these:—

1. Up to the present moment direct current is the only form of electrical energy which seems suitable for traction purposes, and, as is well known, the risk of sparking is greatest with this form.

2. It is practically impossible to guard against sparking, so that the electric locomotive would be a source of danger in a fiery mine. Indeed, the employment of electric locomotives working on the trolley wire system in fiery mines is entirely forbidden in the electric Special Rules.

3. Bare conductors and an earthed return are essential in the modern traction system.

4. The electric locomotive is not very suitable for varying or steep gradients.

With regard to the last-mentioned disadvantage, a system of electric traction, known as the "rack rail" system, and which we shall shortly describe more fully, has lately been introduced into American mines, and is now being exploited by the Goodman Manufacturing Company Ltd., of Cardiff, with a view to its adoption for electric traction in British mines. The system claims to overcome the difficulties arising from varying and steep gradients, and has proved sufficiently successful in America to warrant recognition as the latest successful development in electric mine traction. It is questionable if electric locomotives are to be recommended for use in roadways traversing the goaves in underground workings, as the continual movement of the roof and sides, due to the subsidence, would tend to cause very frequent derangement and injury to the power mains and also to the permanent way.

In addition, the gradual subsidence of the roof would render necessary the constant raising of the timbering at some part of the roadway, in order to obtain sufficient height for the convenient passage of the locomotive and its train. Where the longwall system of working is in operation, therefore, the use of electric locomotives is practically confined to the main haulage levels, which, being invariably driven in the solid coal, are practically immune from strata movements, and can be made permanently of the necessary height and width.

In pillar and stall workings, however, electric mine traction may be in operation from the shaft bottom right to the working face.

That electric locomotive traction will yet find its way into the underground workings of British mines seems to have been recognised by the framers of the electric Special Rules, if one may judge from the prominence given to electric locomotives in their regulations. In shunting operations on the surface there are certainly advantages to be gained by adopting electric locomotive traction.

The system most generally in use for operating electric locomotives underground is the ordinary trolley wire system as adopted in electric tramway installations. In America a combination of the third rail and the rack has now gained considerable footing.

The Trolley Wire System

In this system a bare copper conductor is carried along the centre of the roadway, near the roof, on insulators which are held by projecting arms fixed to the roof or side timber. This trolley wire conveys the current to the locomotive motor, which it reaches through the trolley pole and connections. After leaving the motor, the current reaches the rails through the shafting and gearing, and it returns through the rails of the track to the generating station.

According to the Special Rules for the Installation and Use of Electricity in Mines, "the trolley wires must be placed at least 7 feet above the level of the road, or elsewhere if sufficiently guarded, or the pressure must be cut off from the wires during such hours as the roads are used for travelling on foot in places where trolley wires are fixed." It is evident that with a "live" conductor so near to earth as 7 feet there is great risk to life. In view of this, in the principal mining States in America the pressure allowable on trolley systems is limited to a maximum of 250 volts.

One of the principal objections to underground electric locomotives is the necessity for a much heavier permanent way than is necessary with the ordinary forms of haulage. The weight of the locomotive may be anything from 3 tons to 20 tons, and this necessitates a heavy and an expensive railroad, as, if the locomotive got off the road, serious results might follow.

The usual speed of locomotive trains varies from 6 to 10 miles per hour. Fig. 116 gives an example of electric locomotive traction on the trolley system.

The Rack Rail System

In this system, in addition to the ordinary track, there is a third rail, running in the centre of the way.

This central rail is toothed or notched in a similar manner to the ordinary spur wheel, and in these notches runs a strong sprocket wheel keyed on a separate axle from the axle of the wheels of the locomotive. The rack rail is laid slightly higher than the track rails, in order to allow the teeth of the sprocket wheel to engage with the rack.

Referring to the sketches in Figs. 117 and 118, HH are the ordinary locomotive wheels, AA are the sprocket wheels, C the rack rail, GG the track rails, E the wooden stringers on which the rack rail is supported when it also forms the positive conductor, D the wooden covering to protect the rack rail when a "live" conductor, and F the wooden foundation for the rack rail structure.

The rack rail is built up in sections of 16 feet, and consists of bar iron $\frac{5}{8}$ inch thick, and about 4 inches wide. The notches are from $1\frac{1}{2}$ to $1\frac{3}{4}$ inch wide.

As the entire pulling force of the locomotive is exerted against this rack rail, it is evident that it must be of very substantial construction.

In the rack rail system of locomotive traction, pure and simple, the power is obtained from an ordinary overhead trolley wire, but where the third rail system is adopted the rack rail forms the positive conductor, and the overhead wire is dispensed with.

The rack rail, of course, is adopted in order to enable the electric locomotive to negotiate steep grades. The motors in the rack rail locomotive are generally of the series-wound continuous current type, to give good starting torque.

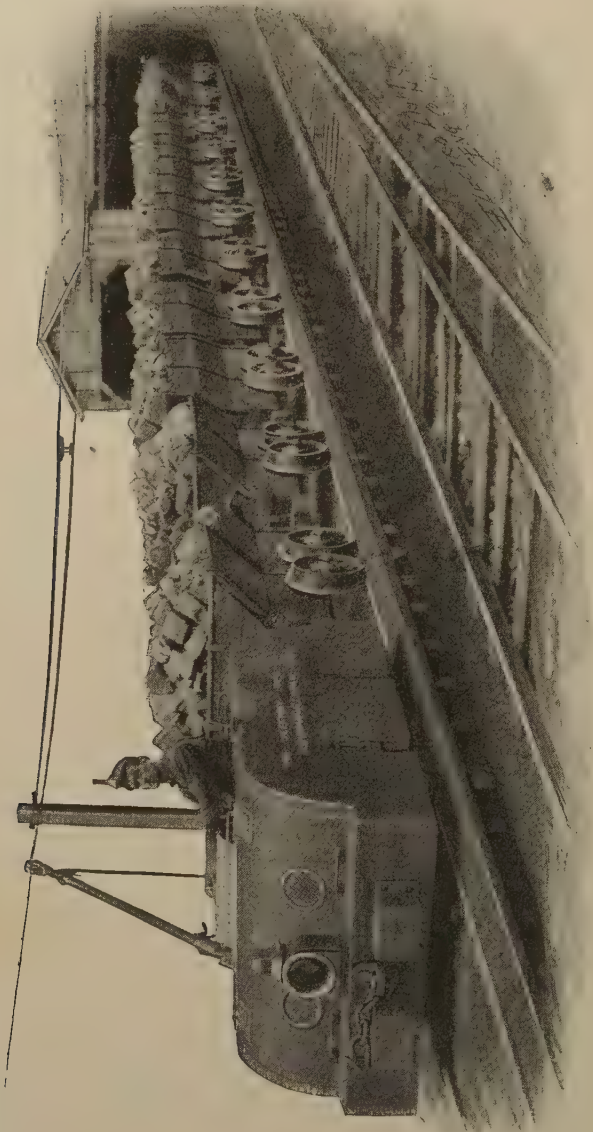


Fig. 116.—Electric locomotive drawing loaded trucks.

Where the rack rail also forms the positive conductor it is so constructed that it is impossible for men or animals to come into accidental contact with it.

For varying grades, where the roadway at some parts becomes practically level, a combination of the rack rail and the traction locomotive is supplied. This type is so designed that when on the inclined portion of the road it works as a rack rail locomotive and

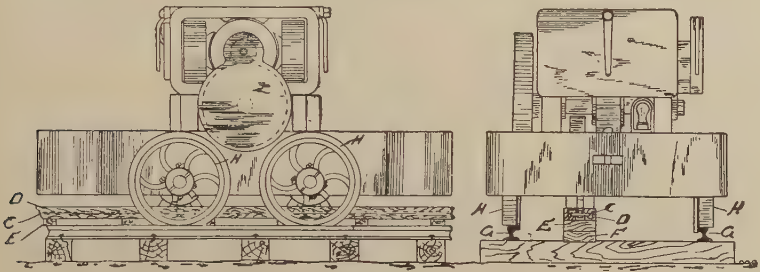


FIG. 117.

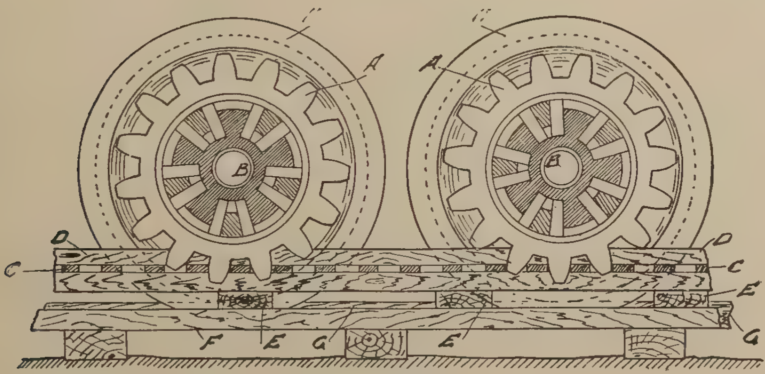


FIG. 118.

on the level as an ordinary traction locomotive—the rack rail on that portion of the road being, of course, dispensed with. The speed of the locomotive motor is reduced to suit the speed of the trains, first by bevel gearing from the armature shaft, and then by spur gearing on the axles of the locomotive.

The rack rail system of locomotive traction is now in very extensive use in the United States of America, and elsewhere.

Its ability to surmount heavy grades gives it a superiority over the ordinary traction system which is readily evident.

Gathering Locomotives

These are so called because they are fitted with apparatus which enable them to run a considerable distance beyond the terminus of the

Fig. 119.—Goodman gathering locomotive.

trolley line, for the purpose of gathering a train of loaded tubs from a group of working places. This "extension" is effected by the employment of a reel of flexible cable which is carried in the rear of the locomotive. When it is desired to go beyond the trolley terminus the

end of the cable is attached to the trolley wire. The flexible cable thus takes the place of the trolley pole for the time being. In this way the locomotive is enabled to work in various situations where it would be undesirable or impossible to carry the trolley line.

As the locomotive proceeds "inbye," the cable is automatically run off the reel at a speed equivalent to the speed of the locomotive, and on returning the cable is re-wound on the reel again.

The two most notable types of this class of locomotive are the Goodman and the Jeffrey.

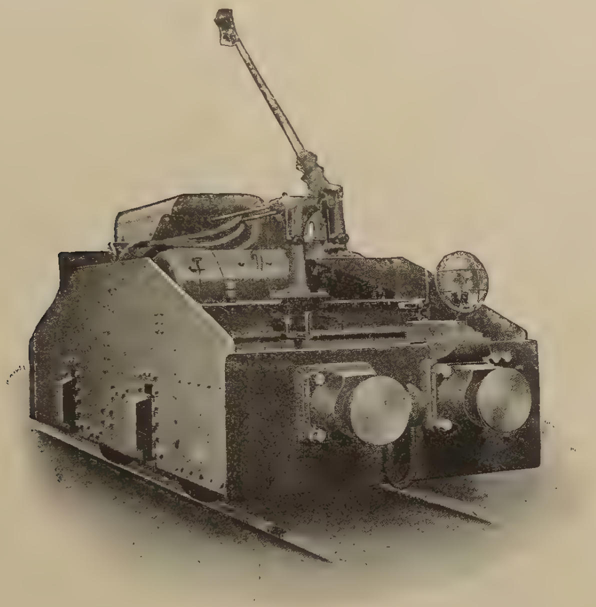


Fig. 120.—Mather & Platt underground locomotive.

In the former type only one motor is used, and this is geared, by means of specially designed gearing, with both axles of the locomotive.

The locomotive has a very short wheel base to enable it to negotiate short curves. Fig. 119 shows the Goodman gathering locomotive.

In the Jeffrey type the arrangements are somewhat similar. Enclosed fuses are used, and also a cylindrical switch controller and a circuit-breaker. The resistance coils are of large capacity, so as to enable continuous control of the speed to be effected without excessive heating.

Fig. 120 shows an underground mining locomotive made by

Messrs. Mather & Platt Ltd. The locomotive, as illustrated, works in a tunnel $5\frac{1}{2}$ feet high and $5\frac{1}{4}$ feet wide. The frame is of steel, as are the axles and tyres, the wheel bodies being of cast iron. There are two entirely enclosed direct current motors, mounted one on each axle, being partly borne on the axle and partly by springs attached to the underframe. The drive is by single reduction gear.

The current, at a pressure of 500 volts, is collected from an overhead conductor by an ordinary trolley arm, the return being by the rails. The locomotive is fitted with a series-parallel controller of the barrel type and electric brake, as well as with a screw hand-brake and the customary lightning arresters and instruments.

The dimensions of the locomotive are as follows. Length, 12 feet; width, 4 feet 5 inches; height, 4 feet 11 inches; wheel-base, 4 feet; gauge of railroad, 2 feet $5\frac{1}{2}$ inches. It has a total weight of 4 tons, and is capable of exerting a draw-bar pull of 1100 lbs. at a speed of 10 miles per hour.

Storage battery locomotives are also sometimes employed in mines underground. The battery consists of a suitable number of secondary cells or accumulators. These are charged from electric mains, and are carried behind the locomotive in a separate carriage. In this system, of course, no trolley wire is required, the locomotive motor being driven from the battery. The system is not very economical.

CHAPTER IX

ELECTRIC PUMPS AND PUMPING

Advantages and disadvantages of the electric motor in pumping—Types of electrically driven pumps: three-throw ram pumps, horizontal and vertical—Description of three-throw pump at Wellsgreen Colliery, with dimensions of pump and calculations for finding capacity of pump, H.P. of motor, etc.—Speed of ram pumps—Reducing speed of motor to suit speed of pumps by belting and gearing—The Riedler pump: its advantages and disadvantages—The Gutermuth valve—The centrifugal pump—High-lift centrifugal pump—Turbine pump—Description of turbine pump at Wellsgreen Colliery—Formulæ relating to the centrifugal pump—Dook pumps—Sinking pumps—Frictional resistance to flow of water in pipes—Some pumping installations.

Electric Pumping

Electricity has been applied to a multitude of mining operations and appliances, but to no purpose has it been more advantageously adapted than to the working of pumping plants of various kinds. A few years ago electric pumping was but little heard of, but so successful and satisfactory were the first experimental innovations in that direction that soon electric pumping began to find great favour in the eyes of mining engineers, until nowadays electrically driven pumps have well-nigh monopolised the field for underground work.

Various reasons might be given why the electromotive-power for pumping should be held to be superior to other forms of driving power, such as steam, compressed air, ropes, hydraulic power, etc.; and the following are a few of the more important advantages over these which electric pumping may be said to possess:—

1. Greater adaptability to the various and varying conditions under which pumping has oftentimes to be carried on underground.

2. The power cables are much more quickly and easily carried to the point of utilisation than are the pipes necessary where steam or compressed air is to be the motive power, and if the work has been efficiently carried out little or no trouble is afterwards experienced in maintaining the cables in good condition, a feature which can seldom be cited in favour of steam or even compressed air pipes.

3. There is less loss in the transmission of electric power than in conveying steam underground.

4. Steam pipes occupy valuable space in a shaft, and are often a source of great danger through the escape of steam, neither of which disadvantages can be laid to the charge of electric cables.

5. The electric motor can adapt itself more quickly and more effectively to sudden or frequent changes of load than can a steam-engine, and the speed of a motor, whether the pump which it is working is throwing its full quantity of water or not, is practically always constant, a most desirable feature in pumping.

The above are some of the most important advantages in electrical pumping, and show that the superiority over other forms is indisputable.

The electric pump, however, has also some disadvantages, and to enable the student to form a better opinion as to its merits, one or two of these may be cited.

The disadvantages are—

1. Loss of power due to the conversion of the electric power of the motor into mechanical power on the motor shaft.

2. Necessity for the intervention of belting or gearing, or both, in the transmission of the power of the motor to the pump, with the consequent loss. (This does not apply to centrifugal pumps and turbines where the use of gearing is entirely dispensed with.)

3. The electric motor is unsafe in a fiery mine, unless very exceptional precautions are taken to prevent sparking, fusing, or arcing taking place in situations where there is the minutest chance of firing gas.

Types of Electrically Driven Pumps

There are various types of the electric pump, and one of the most common as well as one of the most efficient is the three-throw ram pump, an illustration of which is shown in Fig. 121.

It is a most suitable form of pump for pumping large quantities of water from dip workings, and for such work it is very frequently adopted.

The pump may be actuated either through intermediate gearing or by belting and gearing, the gearing being sometimes spur but frequently helical.

The speed of the motor may be anything from 600 to 800 revolutions per minute, while in that time the cranks of each of the three pumping rams would make from 25 to 35 revolutions.

As the name implies, in this type of pump there are three rams, working in three separate working barrels, each separate ram making one backward and one forward stroke during each revolution of the pump. The rams are set 120° in advance of each other, so that at no portion of a revolution can all three rams be drawing or pumping water simultaneously. For instance, either two rams will be pumping water while the other is drawing its water, or one ram will be pumping while the other two are drawing.

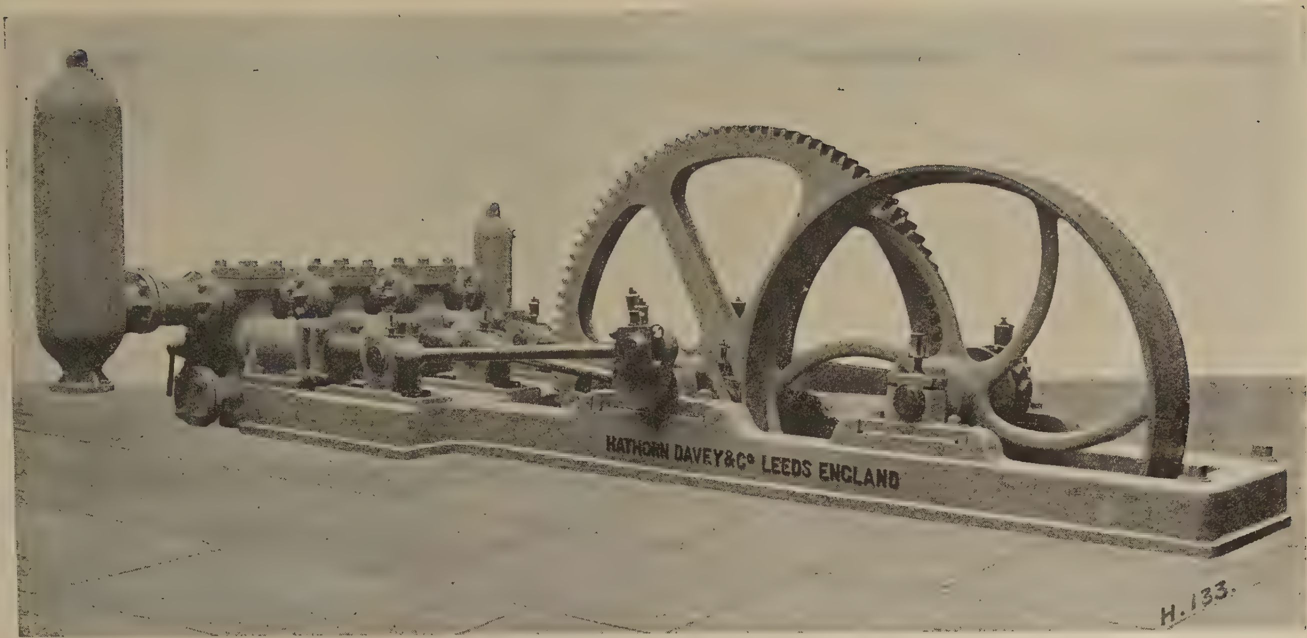


Fig. 121.—Three-throw pump.

Each ram is provided with a separate suction pipe, but all three suctions are connected by a horizontal suction pipe to each other, the horizontal pipe being just immediately above the snore piece. This arrangement ensures the three suctions being kept equally filled with water. The clacks are sometimes of the mushroom variety, but frequently a kind of double-beat clack working on a fixed central spindle is used. After passing through the delivery clacks, the water passes through three short delivery connections into a common rising main, through which it reaches the shaft-bottom sump, or the surface, as the case may be.

The action of the pump is similar to that of the ordinary plunger type.

The three cranks, being set 120° in advance of each other, ensure a steady flow of water in the delivery. This arrangement enhances the efficiency of the pump, and reduces the shock and the wear and tear on the working parts to a minimum. For a pump designed to raise, say, 400 gallons per minute, the suction pipe should be about 9 inches in diameter, delivery 8 inches in diameter, and the rams 10 inches in diameter, with a length of stroke of about 18 inches, and the pump making 35 revolutions per minute.

Fig. 121 shows a horizontal three-throw ram pump, belt-driven by an electric motor, and capable of raising 5000 gallons of water per hour against a head of 600 feet.

Larger sizes of the same type of pump are built by the firm.

Sometimes a three-throw pump with the rams working vertically, and actuated through spur, helical, or worm gearing from the motor shaft, is adopted. This type possesses the advantage of occupying little space.

Electric Three-throw Pump at the Wellsgreen Colliery

An electric pump of the three-throw type has been at work for several years in the dip workings of the above colliery, and the following particulars and dimensions relating thereto may be of interest:—

Pump dimensions—	
Diameter of rams	$7\frac{1}{2}$ in.
Length of stroke	12 ,,
Diameter of main driving shaft	4 ,,
Diameter of smaller helical gear pinion	1 ft. 1 in.
Diameter of larger helical gear wheel	3 ft. 3 in.
Ratio	3 to 1.
Pump revolutions per minute	37.
Speed of rams per minute	74 ft.

The motor is of the bi-polar type, is compound-wound for 90 amperes at 450 volts, and is capable of maintaining a torque equivalent to 50 B.H.P. at a speed of 610 revolutions per minute.

The pump works against a total head of about 450 feet, and throws approximately 190 gallons per minute.

In ordinary working the motor takes 75 amperes at a working pressure of 365 volts, and develops a brake-horse-power of about 36.

The speed of the motor is first reduced by means of a belt-drive, then afterwards by the gearing above mentioned.

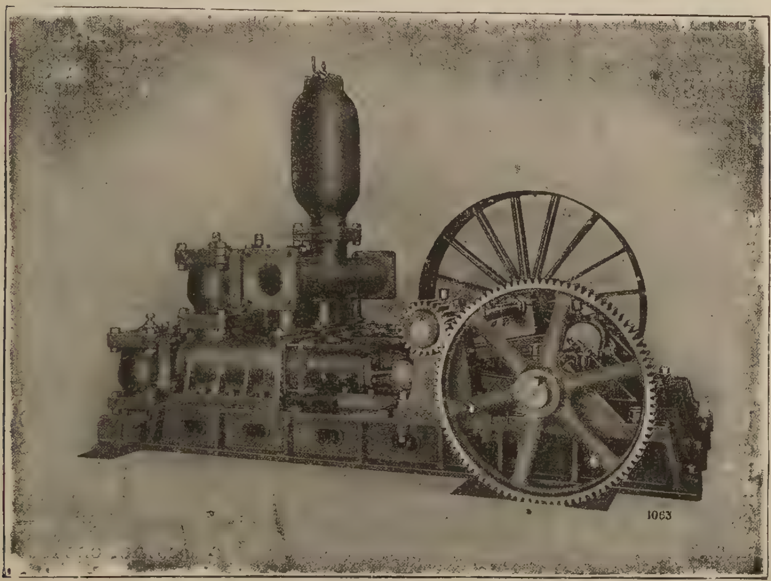


Fig. 122.—Scott & Mountain three-throw pump.

A view of the type of pump installed is shown in Fig. 122, the only difference being that spur gearing is used instead of helical.

Formulæ relating to Three-Throw Pumps

To find the quantity of water that a three-throw pump will deliver, the following formula is used :—

$$G = D^2 \times 0{\cdot}034 \times L \times N \times n.$$

Where D = diameter of ram in inches.
L = length of stroke in feet.
N = number of strokes per minute.[1]
n = number of rams.
G = quantity of water raised, in gallons per minute.

[1] It should be noted that only the forcing strokes of the ram are taken into account.

To find the size of pump necessary to throw a given quantity of water per minute, the speed of pump and number of rams being previously determined, transpose the above symbols to the following :—

$$D = \sqrt{\frac{G}{L \times N \times n \times 0{\cdot}034}}$$

In the above formulæ, 10 per cent. must be added in each case, to allow for slip or leakage of water past valves, etc.

To find H.P. of motor required we must know the quantity of water to be pumped per minute, and the total height to which the water is to be raised.

The formula is—

$$\frac{\text{Quantity in lbs.} \times \text{height in feet}}{33{,}000}$$

This gives the power required solely for the pumping of the water, but a considerable amount of power is lost in the friction of the gearing, slip of belt, and in the motor itself, so that the latter would require to be at least 50 per cent. stronger than the H.P. given in the above calculation.

Speed of Pumps

The speed of motor-driven three-throw and two-throw ram and bucket pumps may be anything from 40 feet per minute up to 110 or 120 feet per minute. Such a high speed as 120 feet per minute is very disastrous to the working parts of the pump, and can only be maintained for very brief periods, owing to the rapid heating up of the bearings and cranks. The usual speed is from 60 feet per minute to 80 feet per minute. Thus a crank with a throw of one foot would have to travel at 30 revolutions per minute, in order that the speed of the ram coupled to it would be 60 feet in the same time.

With so slow a speed as 30 to 40 revolutions per minute, the speed of the motor must, of necessity, be greatly reduced, and this may be effected in various ways, such as by spur gearing only, by spur gearing and belt, or occasionally by worm gearing.

Worm gearing is suitable where the available space is limited, but is perhaps the least efficient of all the methods, owing to the great amount of power absorbed by the friction of the worm and worm wheel.

Spur gearing is also suitable for limited space, but, if the necessary room is available and the atmospheric conditions favourable, a belt or ropes and spur gearing is probably the best method of reducing the speed of the motor to suit the speed of the pump.

Helical gearing is also frequently employed, and gives every satisfaction. The pinions are generally of metal with the teeth machine-cut, but raw-hide pinion wheels have occasionally been tried with much success. There is this to be said in favour of raw-hide pinions,—they are practically noiseless, and that cannot be said of the metal wheel.

The Riedler Pump

The principal feature in the Riedler pump is its mechanically controlled valve. The advantages of mechanical control of pump

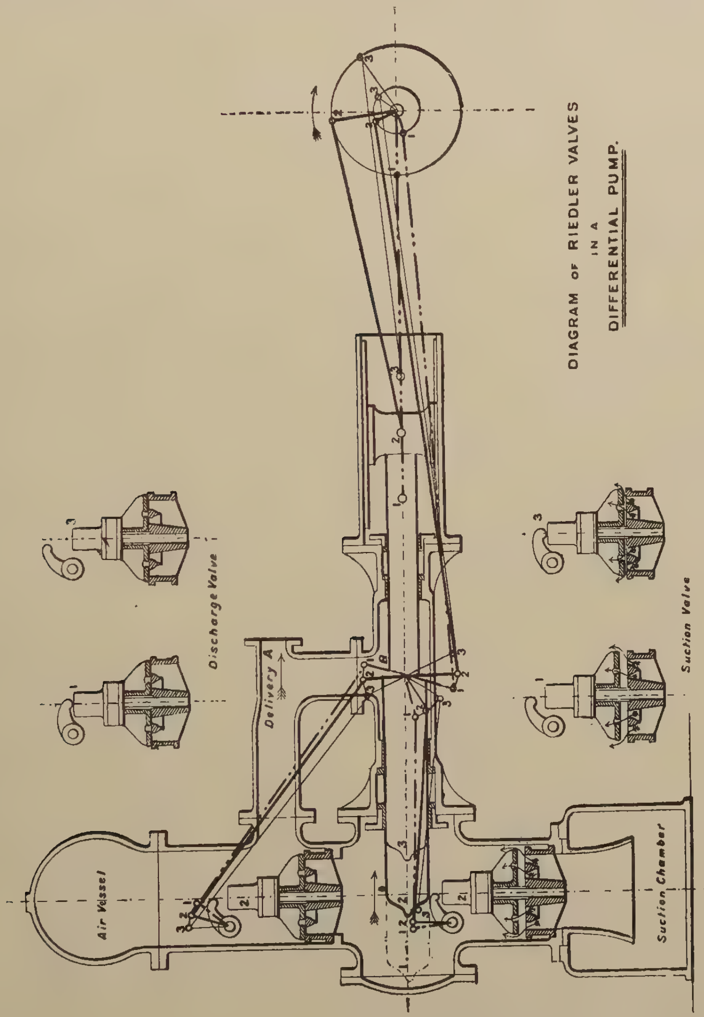


Fig. 123.

valves are readily apparent, and the more important are: (1) Slip is reduced to a minimum; (2) higher efficiency is obtainable; (3) pump

may be run with safety at a higher speed than with ordinary pump valves, owing to the fact that the valve is worked practically independent of the water pressure.

In Fig. 123 is shown a descriptive diagram illustrating the principle of operation of the Riedler valve gear, and the relative position of the plunger and valves. There are two plungers, the large one of which displaces twice the quantity that the small plunger is able to displace. The two plungers form practically one pumping ram, the small plunger being behind the larger. There is only one suction and one delivery valve, as may be seen in the diagram, for practically a double-acting pump. The large plunger discharges half its water to delivery pipe A, and half to barrel B, this on the forcing stroke of the pump.

On the out, or suction stroke, the difference of area of the small and large plungers discharges the contents of B through A.

The operation of the Riedler valve is as follows :—

At the beginning of the suction stroke the valve opens automatically, the controlling fork or tappet having been lifted away from the valve. Near the end of the stroke the tappet on the end of the shaft, actuated by the gear outside, moves downward, and before the plunger starts on its return stroke closes the valve. As the result of this early closing of the valve there is little or no leakage through the delivery clack. The motion for the valve mechanism is ordinarily obtained from an eccentric on the crank shaft.

It will be noticed in the diagram that three positions of the plunger, valves, and gear are represented by the numerals 1, 2, and 3. The numeral 1 indicates the position of plunger, etc. at the beginning of the suction stroke ; 2, their position at the middle of the stroke ; and 3, their relationship at the end of the stroke.

The Gutermuth Patent Valve

The Gutermuth valve is now being fitted to the Riedler type of pump. It practically consists of a sheet of metal coiled in the form of a spring round a central spindle. The spindle is held in its place by means of clamps, or set screws, and the valve is seated in a small recess in the suction pipe or delivery as the case may be.

The outer extremity of the coil of metal forms the valve proper.

The flow of water is sufficient to open the valve, which offers the minimum of resistance to its passage, and when the flow of water has ceased the tension of the spring closes the valve instantly, and with little or no noise. The advantages claimed for the Gutermuth valve are the following :—

1. Simplicity and cheapness.
2. Instantaneous opening and closing.

3. Practically noiseless action.
4. Minimum obstruction of the moving fluid.
5. Wear and tear of valves and seats reduced to a minimum.
6. No guides, guards, etc. are required.

The Centrifugal Pump

The centrifugal pump is the most suitable of all the forms of electric pumps for being motor driven.

It can be coupled direct to the armature shaft of the motor either with a rigid connection or an elastic coupling, preferably the latter, and may be driven at any speed from 500 revolutions per minute up to 2000 revolutions per minute.

It has one conspicuous advantage over the three-throw and similar forms of pump, in that it has no valves, and is in consequence able to pump muddy or gritty water without damaging the working parts or hindering its action in any way.

The centrifugal pump is thus particularly suitable for disposing of the discharge water from coal-washing machines, or for use in sinking or dook-driving, providing the head of water is not too great. The centrifugal pump in its simplest form consists of a number of curved blades arranged round a central axle or shaft, and revolving in an approximately circular casing which is connected up to the delivery pipe or column.

Both in outward appearance and internal construction the centrifugal pump is, therefore, not unlike the ordinary centrifugal fan.

Its action, too, depends upon the same principle, namely, centrifugal force. The water contained between the blades of the pump, by reason of the centrifugal force, is thrown off at a tangent, and finds escape at the orifice leading to the discharge column. A single centrifugal pump coupled directly to an electric motor is illustrated in Fig. 124. Until quite recently the main objection to the centrifugal pump has been the very low efficiency obtained, and as the limit of working head of a single pump is about 70 feet, this has entailed the use of cumbersome combinations for higher lifts. These objections, however, cannot now be urged against the centrifugal pump, as by coupling up two or more single pumps in series it is possible to throw water to any height up to 1000 feet, and still obtain a very good efficiency.

The principal feature in the multiple chamber centrifugal pump is that it consists of one or more sets of vanes or impellers, each running in its own chamber, but upon a common shaft, the delivery pressure of the liquid varying directly as the number of chambers used. Thus, if an ordinary single pump can deliver water against a head of 70 feet, the addition of another chamber will give a final

delivery head of 140 feet, while four chambers will enable the pump to discharge the same amount of water against a total head of 280 feet.

In Mather & Platt's patent turbine pump the water enters the revolving wheel axially, traverses the curved internal passages between the vanes, and is discharged tangentially at the periphery into a stationary guide ring of special construction; this conveys it to the annular chamber in the body of the pump, where the velocity head imparted to the water by the wheel is converted into pressure head.

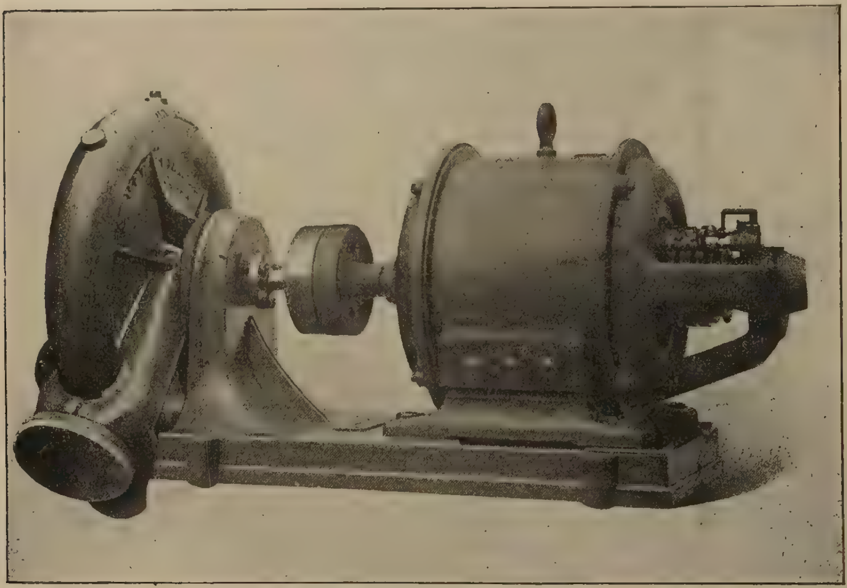


Fig. 124.—Motor-driven centrifugal pump.

From this chamber the water is finally discharged into the pipe lines, or, if the pump be a multiple one, into the second and subsequent chambers. A special feature of this pump is the provision of the stationary guide ring mentioned above; this is fixed concentric with the revolving vanes, and, owing to its design, enables the conversion of velocity into pressure head to be very effectively accomplished, thus increasing not only the possible height of lift, but also the working efficiency of the pump.

This type of pump is well illustrated in Fig. 125.

The ideal source of power for working centrifugal and turbine pumps is undoubtedly the directly coupled electric motor.

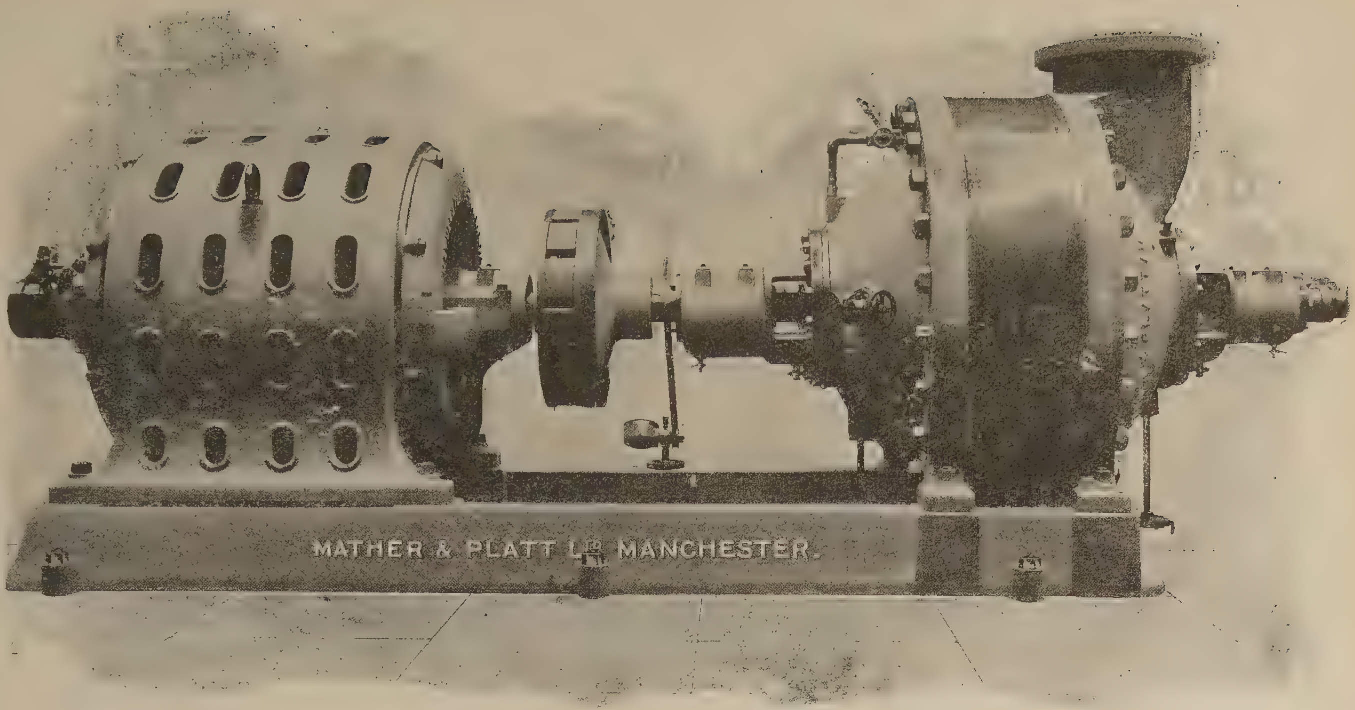


Fig. 125.—Motor-driven turbine pump.

The turbine pump possesses many advantages, conspicuous amongst these being the small number of working parts, compactness, low first cost, and minimum of wear and tear.

Fig. 126 illustrates a quadruple-series centrifugal pump, designed to discharge large volumes of water against a maximum lift of 30 feet. The pumps are arranged two on either side of an electric motor, and are all coupled directly. The centrifugal pump, to work satisfactorily, should have a very short suction piece, or, better still, work entirely under the water.

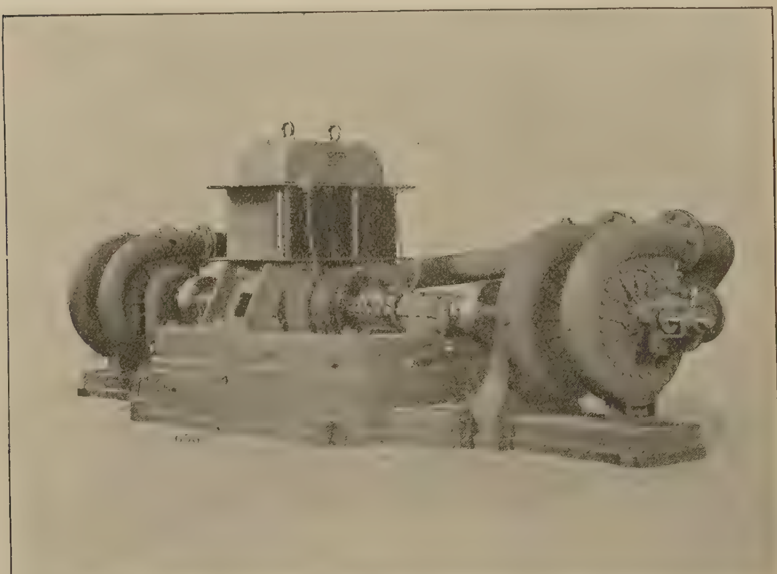


Fig. 126.—Centrifugal pumps in series.

At the Wellsgreen Colliery a motor-driven turbine pump has been at work for several years. The pump consists of five centrifugal wheels in series, each working in separate chambers. The motor is of the direct-current multipolar type, works at a pressure of 480 volts, takes between 130 and 140 amperes at full load, and travels at the terrific speed of some 1400 revolutions per minute. The pump throws about 440 gallons per minute to a height of 504 feet. The turbine is connected to the motor by an elastic coupling, which consists of a belt of leather threaded through suitable perforations in the two flanges (see Fig. 125). At each of the bearings three brass lubricating rings run loose on the shaft to facilitate lubrication.

Formulæ relating to Centrifugal Pumps

In calculations relating to the centrifugal and turbine pumps the following formulæ are adopted :—

Let S = speed of periphery of wheel in feet per second.
H = height in feet to which water is to be delivered.
D = diameter of wheel in feet.
G = gallons of water delivered per minute.
R = revolutions per minute.

(*a*) To find peripheral speed of impeller or wheel in feet per second.

$$S = c\sqrt{H}$$

In the above, c is a co-efficient, usually taken to equal 8·2 for small pumps, and 9·8 for pumps of large capacity.

(*b*) To find diameter of wheel, the quantity and head being given—

$$D = \sqrt{\frac{G \div 6{\cdot}25}{\sqrt{H} \times 0{\cdot}16}}$$

(*c*) To find revolutions of wheel per minute, the head and the diameter of the wheel being given—

$$R = 156\frac{\sqrt{H}}{D}, \text{ for small pumps.}$$

$$\text{,,} = 186\frac{\sqrt{H}}{D}, \text{ for large pumps.}$$

The height to which the simple centrifugal pump will deliver water is theoretically equal to $\frac{v^2}{2g}$. In practice, however, this has to be reduced by 25 per cent.

The horse-power of motor required will be found by multiplying the height in feet by the quantity of water in lbs. delivered per minute, and by the efficiency of the pump and motor, and dividing by 33,000. The efficiency of the pump may be anything from 0·55 to 0·65, and the efficiency of the motor, say, 0·85, the combined efficiencies being thus equal to from 70 to 75 per cent.

Situation of Pumps

In installing electric pumps, care should be taken that the situation is as dry as possible. The pump and motor should both be mounted on raised concrete or brick foundations, and ample provision should be made for storing the water should any breakdown occur in either the pump or the motor.

The storage capacity should be of such dimensions as to allow the

pump to stand for a period of at least forty-eight hours without the water rising so far as to interfere with the motor; if greater storage capacity than this is available, so much the better. The pump-house should be lined with brick and cement, and the roof lined with sheet iron supported on girders.

The pump should be situated as near to the level of the water in the lodgment as possible, keeping in view the desirability of ample storage room.

The type of motor to be used will depend very much upon the form of current available.

Amongst continuous current motors, the compound-wound type is probably the best for pumping, as it gives a good starting torque, and runs at practically constant speed at all loads.

One advantage possessed by the three-phase motor is that it will continue to run even though completely submerged under water. Of course it must not be assumed from this that the three-phase motor may be run under water for prolonged periods with entire immunity from injury. This is not so, but we give it as an advantage peculiar to the three-phase type that it may be made to run under water.

Dook Pumps

In the driving of dooks and mines to the dip of a coal seam a good deal of water is sometimes made, and in order that the work can

Fig. 127.—Ram pump in dook workings.

be expeditiously proceeded with it is imperative that the face of the working be kept constantly dry.

For this class of work motor-driven pumps are specially suitable, owing to the small space which they can be arranged to occupy, and

the ease with which they can be carried forward as the face of the working advances.

The three-throw pump and the centrifugal pump are two of the best for the purpose.

The centrifugal does good work for lifts up to, but not exceeding, 60 feet, but for higher lifts the three-throw pump is perhaps preferable.

The three-throw is sometimes mounted on a portable bogie, so that it can be the more easily carried forward when necessary, or it can be arranged to work in a recess cut into the side of the dook or mine, conveniently near the face of the working. The pump must, of course, be brought nearer to its work whenever the rams attain a working height above the level of the water in the sump hole of over 20 feet.

Fig. 127 shows a ram pump driven by a continuous current motor for use in dook workings. The switch gear and meters are situated in the rear of the motor, and the entire apparatus is carried on a bogie bedplate so as to expedite transportation. High-lift centrifugal pumps are also very suitable for this class of work.

Sinking Pumps

Electrically driven pumps are now being employed in sinking operations and also in the unwatering of old shafts, and would seem to be eminently suited to such work.

For this class of work, pumps of both the plunger type and the centrifugal have been adopted.

One of the latest types of electrically driven sinking pumps is the one shown in Fig. 128. The pump is of the duplex single-acting plunger type, driven by a motor of damp-proof construction. The speed reduction is made through a raw-hide spur pinion on the motor shaft, which gears into a cast-iron wheel on the second motion shaft. A pinion on the second motion shaft engages with another gear wheel on the crank shaft of the pump. The motor is former-wound, and can be built for continuous or polyphase currents, and for any voltage. The pump and motor are slung in the shaft from a capstan engine or winch by means of the two eye-bolts shown above the motor. The pump is a very compact, convenient, and efficient apparatus.

Another type of sinking pump is illustrated in Fig. 129. This pump is of the centrifugal type, the pumping wheel being fixed on a vertical spindle to suit the situation. The motor is totally enclosed and water-cooled, the whole of the water delivered by the pump being passed through an annular space provided in the motor casing.

This form of cooling is quite as efficient as the usual method of

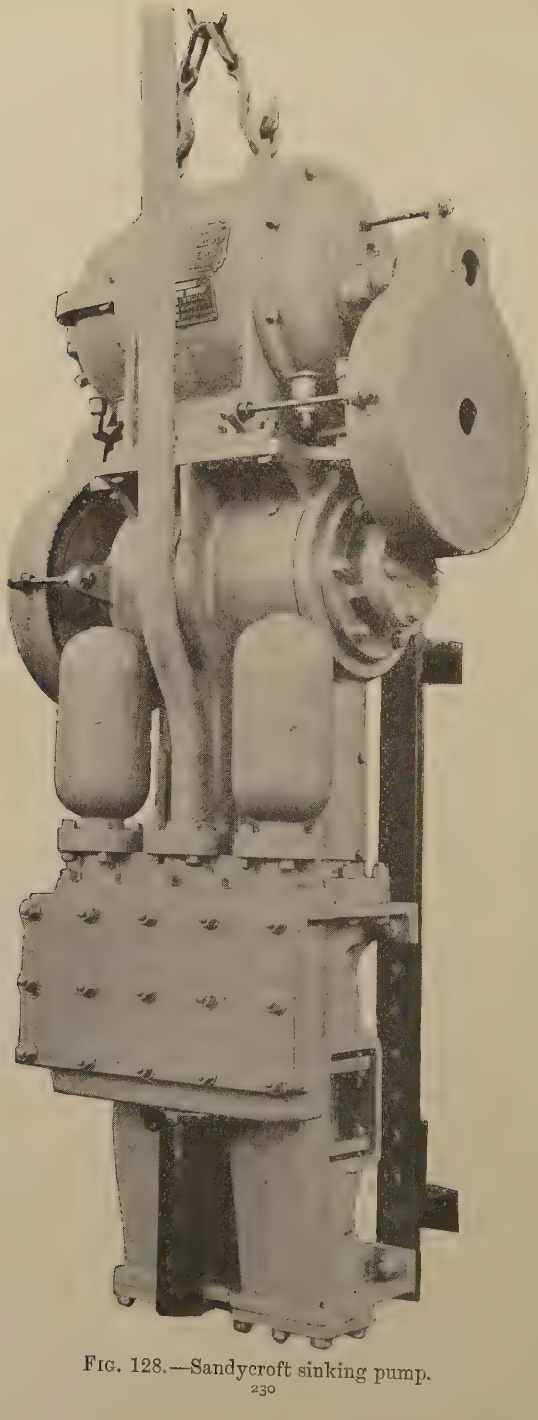


Fig. 128.—Sandycroft sinking pump.

depending upon air ventilation, and is much safer for mining work, as it enables the motor to be totally enclosed, and so protects the

Fig. 129.—Turbine sinking pump.

electrical portion of the machine from damp or risk of mechanical injury. The pump is slung as shown in the illustration.

Frictional Resistance to Flow of Water in Pipes

For all types of pumps the frictional loss for the size and length of pipe (both suction and discharge) must be calculated and allowed for in fixing on the size of pump to use and the power required to drive.

The accompanying table, for which we are indebted to Messrs. Scott & Mountain, gives the loss per 100 feet run for varying sizes

of pipes when passing water at any given speed. The gallons delivered per minute are also stated.

As a proof of the usefulness of such a table, let the following example suffice :—

A pump is required to deliver 250 gallons per minute through a 5-inch pipe to a head of 300 feet at a speed of 5 feet per second. A reference to the table will show that, at 5 feet per second, a 5-inch pipe will pass 255 gallons per minute with a loss of 2·05 per 100 feet.

This, for a head of 300 feet, is equivalent to 6·15 feet, and the pump must therefore be designed for a head of, say, 307 feet.

Loss in Feet-Head per 100 Feet Run due to Pipe Friction.

Speed in Feet per Second.	Gallons per Minute, and Loss in Feet per every 100 Feet.	Diameter of Pipes in Inches.							
		2	3	4	5	6	8	10	12
3	Gallons per minute .	24·6	55	97·9	152	220	391	612	879
	Loss in feet . .	2·04	1·35	1·02	0·815	0·679	0·509	0·407	0·339
4	Gallons per minute .	32·8	73·6	130	204	293	522	817	1176
	Loss in feet . .	3·42	2·28	1·71	1·37	1·14	0·856	0·685	0·573
5	Gallons per minute .	41	91·7	163	255	367	655	1017	1466
	Loss in feet . .	5·1	3·43	2·57	2·05	1·71	1·28	1·03	0·855
6	Gallons per minute .	49·2	110	195	305	441	780	1223	1765
	Loss in feet . .	7·15	4·78	3·59	2·87	2·39	1·79	1·43	1·20
7	Gallons per minute .	57·4	128	228	365	514	911	1428	2059
	Loss in feet . .	9·52	6·38	4·77	3·81	3·18	2·38	1·90	1·59
8	Gallons per minute .	65·6	147	260	408	586	1044	1634	2346
	Loss in feet . .	12·2	8·16	6·12	4·9	4·09	3·06	2·45	2·04

Pumping Installations

One of the most up-to-date installations of electrical pumping machinery was recently carried out by Messrs. Scott & Mountain, of Newcastle-on-Tyne, at the Manton Colliery, Worksop.

The power is generated by three sets of horizontal coupled compound slow-speed steam-engines, with crank-shaft alternators, each set being capable of developing 470 effective H.P., and 360 K.V.A. at the alternators.

The total K.W. obtained from each generator, with a power factor of 0·9, is 330. The current is three-phase, at a periodicity of

50 cycles per second, the volts per phrase being 500, and the amperes per phase 428.

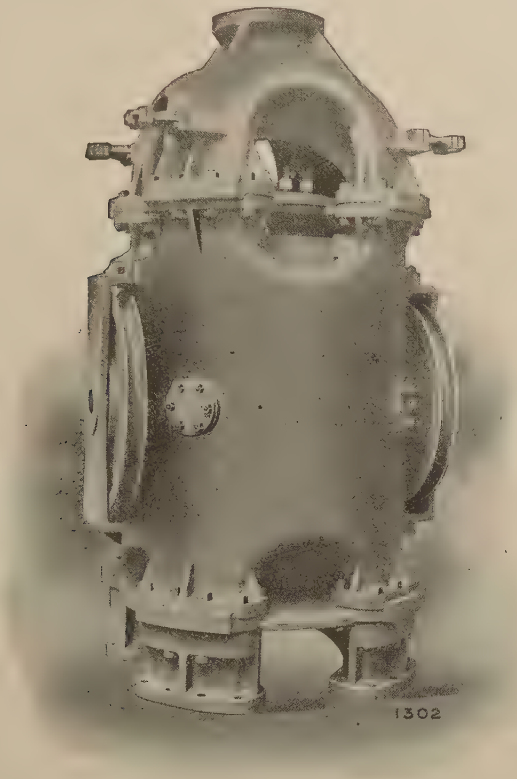


Fig. 130.—Water-cooled motor of turbine sinking pump.

There are altogether five sets of pumps at work. The following are the dimensions of the sets :—

	Top Level.	Bottom Level.
No. of pumps . . .	2	3
Diameter of each ram .	14 in.	14 in.
Length of stroke . . .	18 in.	18 in.
Revolutions per minute .	25	31
Gallons per minute, each .	900	733
Total do. . .	1800	2200
Vertical head . . .	285 ft.	360 ft.
Horse-power of each motor .	120	120

The pumps are of the three-ram type illustrated in Fig. 122.

Another important departure in the adaptation of electric pumping to different situations is illustrated in an installation of electric turbine sinking pumps recently carried out by Scott & Mountain at the Dover Colliery, belonging to the Kent Collieries Ltd.

In the course of sinking, a considerable quantity of water was made, and as the work of sinking, and also the tubbing of the shaft, must be done simultaneously with the pumping, it is most essential that a system of pumps be adopted which occupies a minimum space in the shaft, and can also be readily raised or lowered according to the level of the water. After mature consideration it was decided to adopt motor-driven centrifugal pumps of the vertical spindle type. There are two sets of these electrically driven centrifugal pumps at work. Each pump is capable of delivering 1000 gallons per minute against a head of 640 feet.

The pumps are of the type illustrated in Fig. 129. Each pump consists of four stages, the impellers being of gun-metal, with gun-metal guide plates for reducing the internal friction of the water. The pump spindle is supported by means of a special ball bearing, and is connected direct to the motor shaft by means of a flexible coupling.

The motors are a special feature of the installation. They are totally enclosed and water-cooled, the whole of the water from the pumps being passed through an annular space provided in the motor casing. The motor is shown in Fig. 130. Each motor is capable of developing 300 B.H.P. at 1440 revolutions per minute, the pressure at the terminals being 2400 to 2500 volts.

CHAPTER X

ELECTRIC-POWER DRILLS AND UNDERGROUND COAL CONVEYORS

The application of electric drills to mining operations—Rotary drills—The Jeffrey drill—The Waterhouse drilling machine—The Corlett patent rotary drilling machine—The Crescent coal drill—Percussive or reciprocating drills—The Marvin-Sandycroft electric rock drill—The Siemens reciprocating drill—Electric underground coal conveyors—Their application and advantages.

Electric Drilling Machines

Up to very recent years, compressed air monopolised the field as the motive power for actuating rock and coal power-drilling machines, but since the advent of the twentieth century, so rapid has been the development of electric-power drills, that quite a host of different makes are now on the market. Some of those machines have proved surprisingly successful, especially for drilling shot-holes into coal and shale, where the rotary motion, characteristic of the majority of present-day electric drills, is certainly more applicable than it has proved to be in harder material, such as rock, etc.

As has been remarked, the greater number of the electric drilling machines at present on the market produce a rotary motion on the drilling tool, but there are also a few examples whose action is percussive, and the best of these will be noted presently.

The percussive drill is most suitable for boring in the harder metals, such as rock, sandstone, whin, granite, slate, etc.

Undoubtedly the adoption of electric-power drills for special purposes may be arranged to effect a considerable saving.

In narrow work the drilling of shot-holes is generally a constant necessity, and in sinking shafts, stone mines, cross-measure drifts, and similar undertakings, drilling is absolutely indispensable. The use of the electric drill in such operations, and in nearly all undertakings where shot-hole drilling must necessarily be extensive, is certainly calculated to effect considerable economy. Instances are on record where the rate of travel in stone mines and cross-measure drifts has been more than doubled by the substitution of electric-power drilling for hand boring.

The Jeffrey Electric Drill

This drill is in very extensive use, especially in the anthracite mines of America.

The motion is rotary, and is suitable for drilling in both coal and rock; the only alteration in the machine for use in hard material

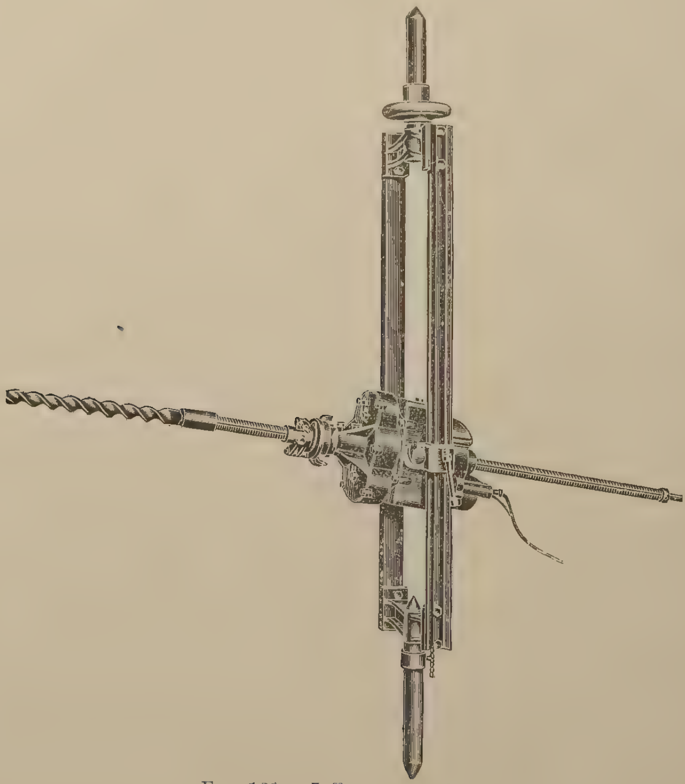


Fig. 131.—Jeffrey rotary drill.

being a reduction in the cutting speed of the tool. Fig. 131 shows the Jeffrey drill for use in coal.

The motor is series-wound, to give sufficient starting torque, and is geared to the drill in the ratio of about 5 or 6 to 1, according to the hardness of the coal.

The drill is fitted into the end of a long screw. Small grooves traverse this screw, and into these projecting feathers on the boss of the larger gear wheel are made to fit.

The feed is obtained by a nut through which the long screw worms its way while the drill is in motion. The nut is held in a specially designed friction-slipping clutch, which is so adjusted that the drill slips when any unusually hard substance is encountered in the drill hole.

The thrust is taken up by a ball race on the front of the machine. The frame is made in different lengths to suit the various seams. The hand wheel above the standard in the illustration runs on a short screw, and by its means the frame can be securely fixed. Holes may be bored in any direction and at any inclination within a range of 90 degrees. The total weight of the coal drill is only 180 lbs., and it is comparatively easy to handle.

The machine can drill a hole 2 inches in diameter and 6 feet deep in about $2\frac{1}{2}$ minutes in fairly hard coal, including the changing of the drills and the cleaning of the drill hole.

These drills are very suitable for boring exploration holes in approaching old workings, a hole 21 feet deep being finished in little over an hour.

They have also been designed for working in rock, and the only important alteration made is the inclusion of a double reduction gear to allow of a slower feed.

The machine as a whole is also much stronger, and weighs complete about 300 lbs.

It feeds at the rate of 2 feet in $1\frac{1}{2}$ minute.

The standard voltages of the motors for the Jeffrey drills are 220 and 500, continuous current, and the motors are of $1\frac{1}{2}$ to 2 B.H.P.

The Waterhouse Drilling Machine

This machine is primarily designed for boring shot-holes in coal, and is not intended for drilling in rock.

It is made by the Diamond Coal-Cutter Co., and, as seen in the accompanying illustration, Fig. 132, is fitted to Waterhouse's patent carriage, by which means it can be very readily moved from place to place.

The motor is wound for anything from 400 to 500 volts, and a starting switch with automatic overload and no-voltage release is fitted to the stand.

The motor is entirely enclosed. The motor and drill are mounted on a revolving stand, and can be readily raised or lowered, and will bore at any required angle.

Three drills are provided, which bore a $1\frac{3}{4}$-inch hole to a depth of 5 feet. This little machine is admirably suitable for the boring of shot-holes to bring down the coal after it has been cut by a coal-cutter. In one instance, where shot-holes had to be bored every 7 feet on a 500 yard longwall face to bring down the coal after the cutter, over

500 holes were bored per week by the Waterhouse drill. The cost of boring the holes by hand 4 feet 6 inches deep was about 5d. per hole.

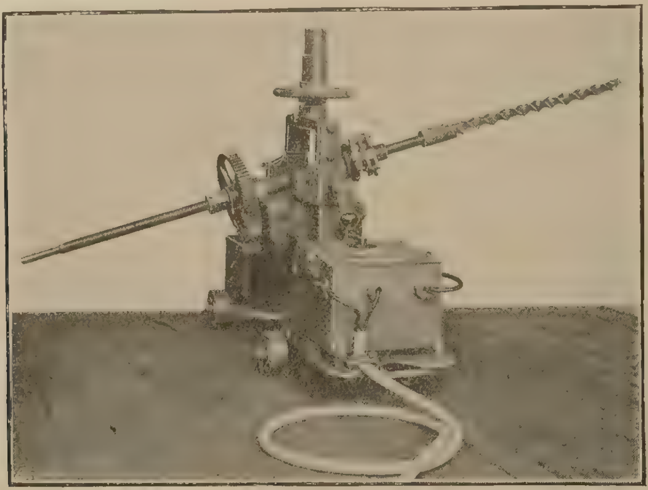


FIG. 132.—Waterhouse drilling machine.

With the Waterhouse electric drill the cost per hole was reduced to $1\frac{3}{4}$d., representing a saving of over $1\frac{1}{2}$d. per ton.

THE CORLETT PATENT ROTARY DRILLING MACHINE

This electric drilling machine is designed for boring in coal and moderately hard rock. Fig. 133 shows the machine fitted ready for boring, and Fig. 134 shows the drill in plan and in section.

The motor may be either of the continuous current or the polyphase type.

The standard continuous current motors are series-wound, suitable for 110, 230, or 500 volts, and are gas- and waterproof. The standard polyphase motors are suitable for 500 volts at 40 periods. The motor runs at a slow speed, allowing the telescopic shaft, which is geared into the boring machine at its outer end, to be coupled direct to the motor spindle. The boring screw is operated through bevel gearing from the telescopic shaft. A friction clutch which can be set to slip at any desired overload is fitted on the spindle. The controlling switch is enclosed in a gas-tight case, and is fitted with magnetic "blow-outs." The thrust bearing is of the conical roller type, and is built for a working pressure of 6 tons. A feed gear arrangement

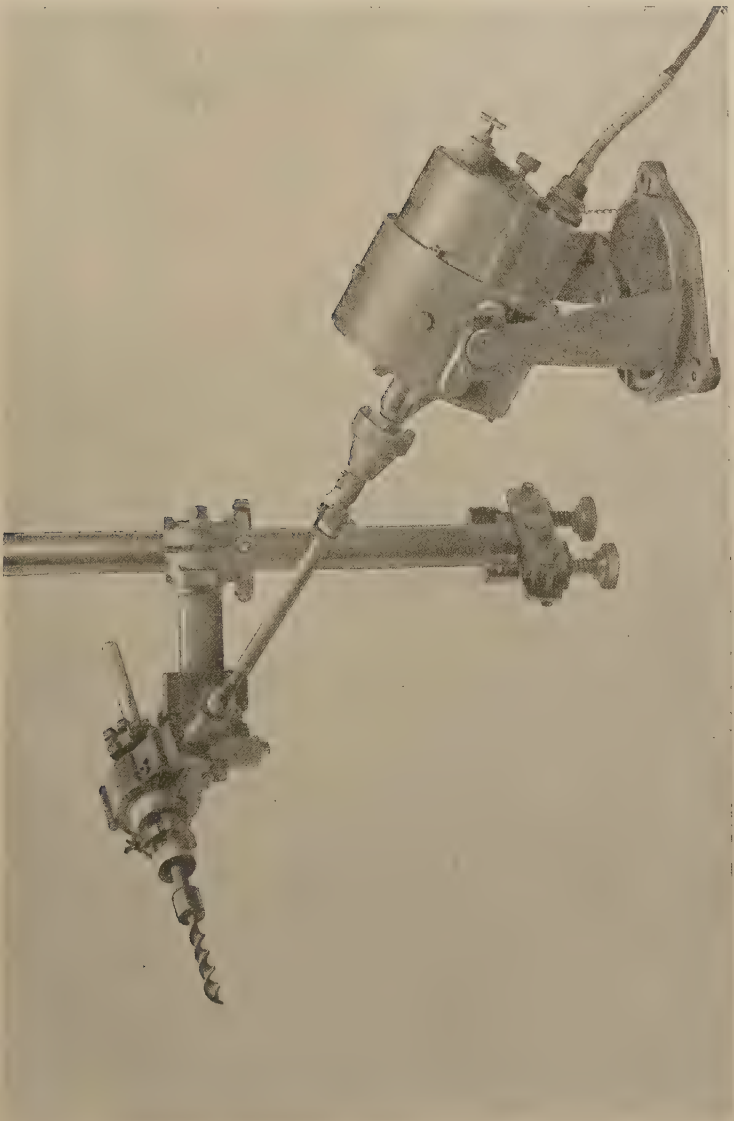


FIG. 133.—Corlett rotary drilling machine.

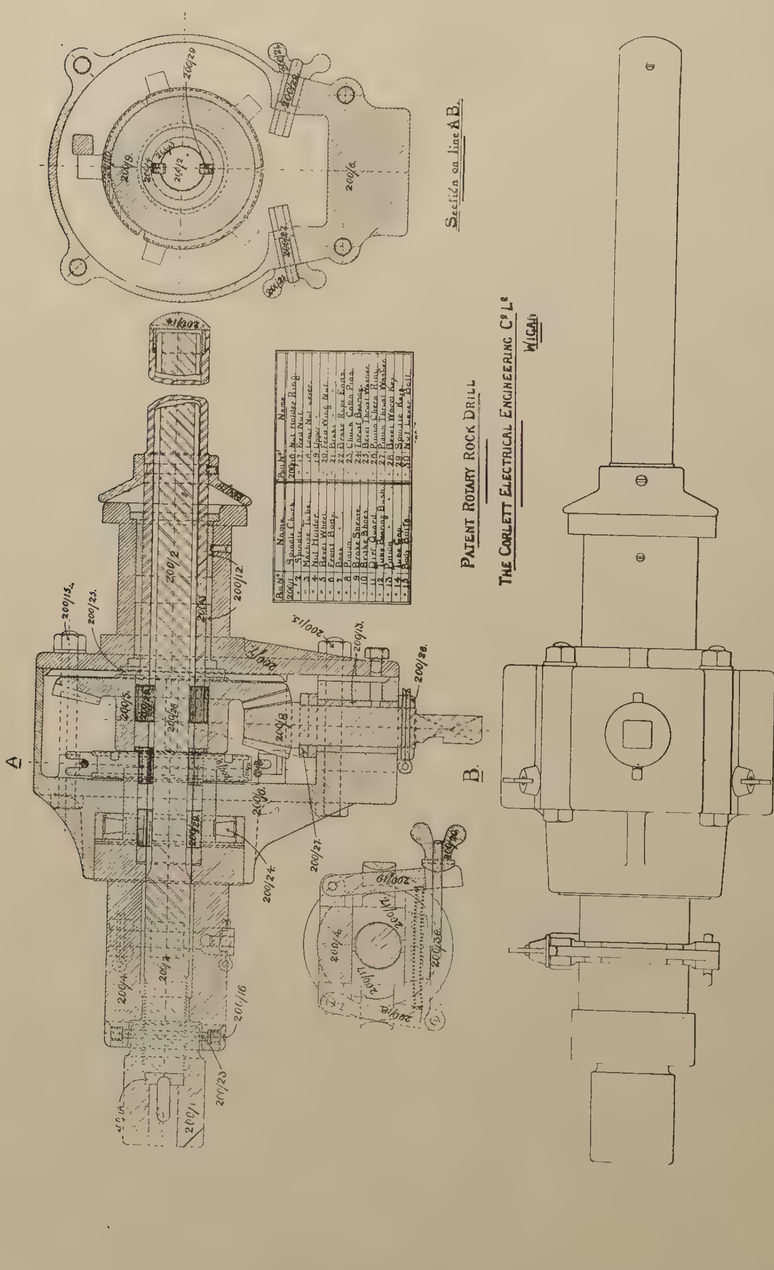


FIG. 134.—Section and plan of Corlett drilling machine.

somewhat similar to that described in connection with the Jeffrey drill is provided, and the length of travel without changing a drill is 22 inches.

The Corlett machine has been in practical use for over three years, and is at work at collieries in all the most important of the English coal-producing shires.

The Crescent Coal Drill

This machine is particularly suitable for drilling in coal.

The general form of the machine is clearly illustrated in Fig. 135.

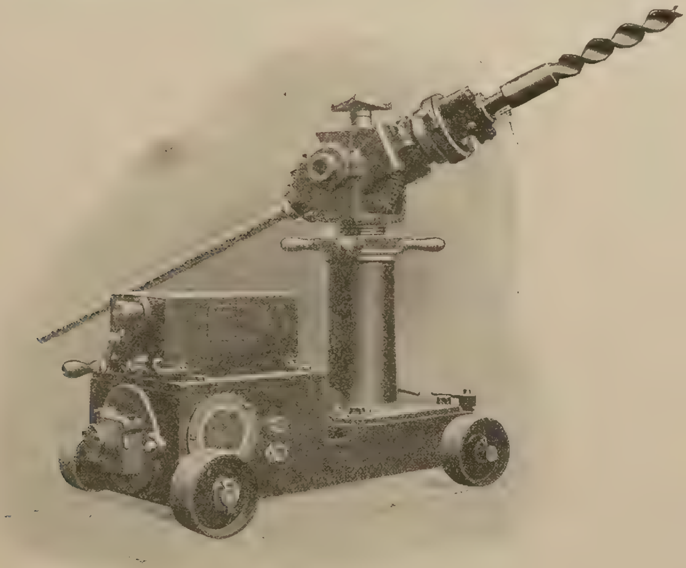


Fig. 135.—Crescent coal drill.

It is built up on a steel box carrying the motor and the gearing. The drill spindle is fitted in a universal swivelling head fitted to the top of a screwed pillar, this latter being provided with a four-handled nut for adjustment in a vertical direction. The drill can be set to bore in any direction radially—upwards at any angle to 30 degrees, and downwards to 20 degrees, and the driving wheels are always in full gear whatever direction the drill is set to. The machine is held in position by being wedged up to the roof, the handled nut being used for this purpose. The spindle is provided with a pair of clasp nuts and a friction feed device, which gives a complete range of speed from zero to the full pitch of the feed screw. The motor is of

2 B.H.P., and can be built for any voltage up to 600, and for either continuous or alternating current. The whole machine is self-contained, runs on four travelling wheels, weighs about $3\frac{1}{2}$ cwts., and may be transported from place to place with ease.

Percussive or Reciprocating Drills

One of the best of the percussive type of electric drills is that patented by the Sandycroft Foundry Co. Ltd., and known as the Marvin-Sandycroft electric rock drill.

The reciprocating or to-and-fro motion produced in the drill holder or piston of this machine is dependent for its action upon the property possessed by a solenoid or coil of wire through which an electric current is passed of drawing into its cylindrical core any suitable piece of metal which comes within the influence of its magnetism. In the Marvin-Sandycroft drill (see Fig. 136), two coils of copper wire (3) are used, each insulated from the other by mica, and enclosed by a long tube of steel, the whole forming practically one powerful solenoid of copper and iron nearly two feet in length. In the interior of this tube or solenôid is a loosely fitting core of mild steel (1, 2, and 4), which is provided at its outer end with a chuck (6) for holding the tool. This tube core carries the drills, and has a stroke of from 6 to 8 inches. The action of the drill is as follows:—

The electric current, in passing through first one coil of wire and then the other, induces or sets up an alternate magnetism, which, acting on the loose steel core or plunger, pulls the latter backwards and forwards in the solenoid in rapid alternations. The constant alternation of the current in the two coils is produced in the generator itself, and conveyed to the drill by a three-core cable, or even through three bare copper conductors, the voltage being very low, only 145 volts.

By means of the rifled bar (8) and ratchet wheel (9) such as is common to most reciprocating drills, the drilling plunger is given a slight turn after each blow. To enable a portion of the energy stored in the plunger during its backward stroke to be utilised in increasing the force of the forward stroke, a strong recoil spring (7) is fixed in the rear. There is also a feed screw arrangement for keeping the drill up to its work. The cables conveying the current are connected up to the wires of the solenoid coils by means of the brass plugs (10). The number of strokes per minute depends upon the speed of the generator. The drilling plunger makes one complete backward and forward stroke for each revolution of the dynamo. The average number of strokes varies from 350 to 385 per minute.

The force of the blow struck is probably as powerful as that of some well-known air-power drills, and it is claimed that the Marvin-Sandycroft machine will give the same blow with only half the horse-power required by the air-drill.

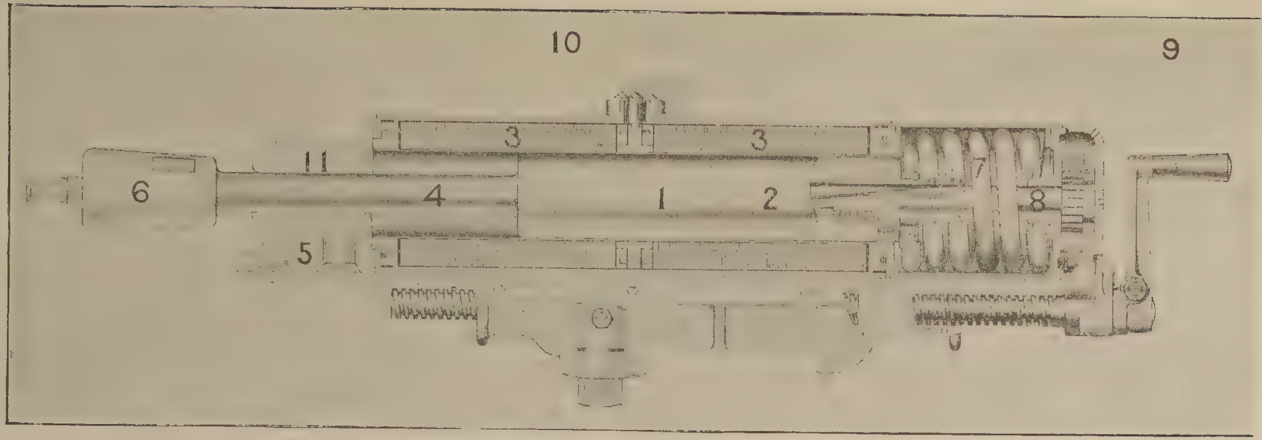


FIG. 136.—Marvin-Sandycroft reciprocating drill.

As will have been learned from the above description, there is neither motor, gearing, shafting, glands, nor valves in the Marvin system, and the absence of these certainly renders the drill an exceedingly simple and reliable machine.

Several of these drills have been in use in this country for some time, and most of them have provided substantial proof of the efficiency, reliability, and mechanical durability of this drill.

The machine is provided with a tripod, column, or stretcher bar, as the situation may demand.

The Siemens Reciprocating Drill

Messrs. Siemens also manufacture an electric drill of the percussive type (Fig. 137).

Unlike the Marvin drill, however, the drill bar or plunger in the Siemens machine is driven by a connecting rod and cross head from the counter shaft of a motor. Heavy spiral springs are interposed between the cross head and the drill bar in order to take up some of the shock of reversal in the movements of the bar. The bar is screw-threaded, working in a nut to produce partial rotation of the drill in one direction during its forward stroke. A feeding arrangement worked by hand is provided. The motor, which may be wound either for continuous or three-phase current, and for any voltage up to 300, actuates the drill through spur gearing, one reduction being sufficient to reduce the speed of the motor to the speed of the drill. A friction clutch is used to throw the motor into gear after it has attained full speed. Arrangement is made by means of a spring device in the clutch, so that at a certain overload the clutch will slip and so relieve the motor from undue strain. The motors are either of 1 or 2 H.P. according to the size of the drill, and as the number of strokes per minute of the latter varies from 400 to 500.

Electric Underground Coal Conveyors

The electric coal conveyor is an appliance designed for the purpose of carrying the coal along the working face to a common main gate-road, dispensing entirely with the need for making and maintaining a large number of intermediate roadways.

It is used at the present time in many collieries throughout the country, and in many instances has proved to be of good service in increasing the output and in reducing the cost of working.

Its advantages are most conspicuous in the working of thin seams where the cost of ripping and repairing gate roads is generally very high. Without the conveyor system the gate roads are usually every 10 to 12 yards, whereas with an electric coal conveyor at work the

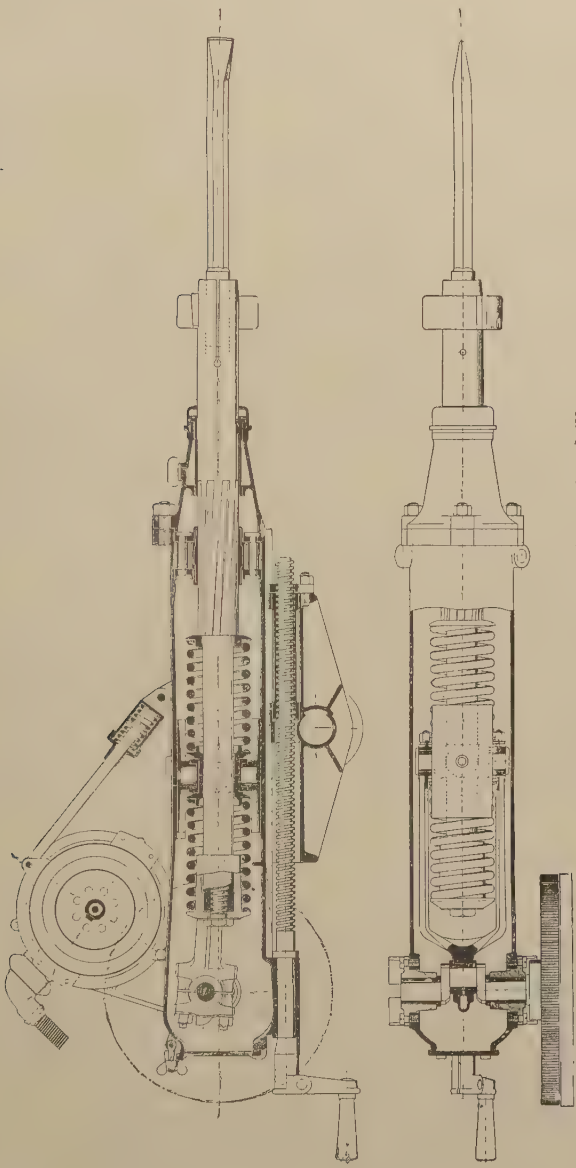


FIG. 137.—Siemens reciprocating drill.

distance from gate road to gate road may be anything from 60 to 100 yards.

To obtain the full economic advantage claimed for the conveyor, it should be worked in conjunct with an electrically driven coal-cutting machine.

The conveyor itself is built up in 6 feet sections. The outer framework is of angle iron about 3 inches on the side and $\frac{3}{8}$ inch thick, and the sections are bolted together, enabling speedy erection or

FIG. 138.—Underground coal conveyor, showing troughs and framework.

dismantling to be accomplished. The troughs, also in 6 feet lengths, are carried on the angle iron framework, and one end of each trough is slightly dished so as to readily fit into its neighbour (see Fig. 138). The conveyor chain is made up of links bolted together to form an endless belt. The larger pieces of coal thrown on the conveyor are carried along on the top of the chain, and the small coal which falls between the links is scraped along the bottom of the troughs by scraper projections bolted to the links. The height of the conveyor is about 10 inches, but at the discharging and tail ends, where the toothed or sprocket wheels are, it is considerably higher—from 1 foot 6 inches to 1 foot 9 inches.

The chain at either end of the conveyor passes over a sprocket drum, the teeth on the drum engaging with the links of the chain. The lower half of the chain is supported on bars fixed at intervals between the lower framework.

The conveyor chain is driven through spur gearing from Renold chain drive, by a totally enclosed motor of 8 to 10 B.H.P., running at 600 revolutions per minute. As the chain cannot slip in the event of any sudden load or "sticking," some provision had to be made to prevent damage in such contingency, and this necessary saving

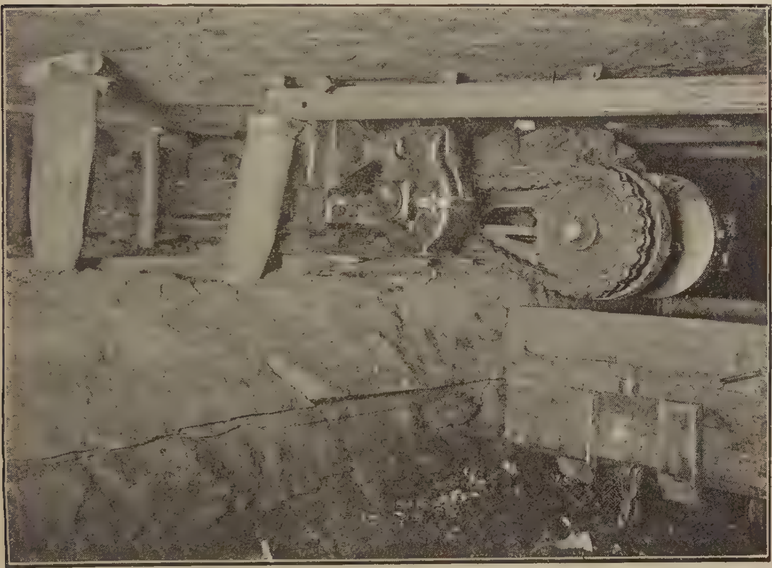


FIG. 139.—Conveyor discharging coal.

device takes the form of a copper shearing key, which is inserted between the driving discs outside the gear case. The copper shearing key can be readily replaced after a stoppage due to "sticking." In addition to the copper shearing key, an automatic cut-out is also provided, which momentarily breaks the circuit on the passage of an excessive amperage. At the tail end of the conveyor a screw-tightening arrangement is provided, with mooring chain for securing to timber. The overall width of the conveyor is 19 inches.

The conveyor is used in lengths of 60 to 100 yards, the best practical working length being 80 to 90 yards. A main gate-road, preferably with a double road, is necessary at the discharging end,

and this should be driven and kept constantly a few yards ahead of the coal face to allow of a continuous supply of empty tubs.

In thin seams a foot or more of the pavement has to be lifted in order to have the top of the tub low enough to allow the discharging end of the conveyor to project over it (see Fig. 139).

Some of the advantages to be gained by the adoption of the conveyor system are as follow: (1) Greater output per man; (2) consequent reduction of cost of "getting"; (3) great saving resulting from the few gateways necessary; (4) quicker advance of working face; (5) introduction of larger tubs made practicable; (6) less "putters" or "trammers" required; and (7) increased output from a given area of coal.

The coal conveyor is not suitable for working under a tender roof, owing to the width of open space necessary for accommodation of the conveyor. Where the roof is good, however, very little trouble is experienced. The conveyor is advanced with the face, being moved forward either in sections without disturbing the timber or (when the roof allows of several props being withdrawn) slued forward from either end, the structure having sufficient flexibility to allow of this being done.

The Diamond Coal-Cutter Company are the principal manufacturers of the Blackett conveyor, the chief features of which are embodied in the above description.

The following particulars relating to the actual working results obtained through the employment of coal conveyors underground may be found of practical utility:—

Output of the Blackett Conveyor at Newburgh Colliery.[1]

Period.		Days.	Output. Totals. Tons.	Output. Per Shift. Tons.
1904.	July	11	346·4	31·5
	August	22	954·6	43·4
	September	24	1,046·7	43·6
	October	22	1,135·1	51·6
	November	23	1,473·6	64·0
	December	22	1,047·3	47·5
1905.	January	21	385·5	18·3*
	February	21	589·3	28·0*
	March	23	1,244·1	54·1
	April	17	1,189·6	70·0
	May	22	1,615·3	73·4
	Totals	228	11,027·5	48·3

* Hand-holing and conveyor moved forward through troubles.

[1] Given by Mr. C. H. Merivale in the discussion on Messrs. W. C. Blackett and R. G. Ware's paper, "The Conveyor System for Filling at the Coal Face," *Trans. Inst. M.E.*, vol. xxviii., 1905.

The length of face was 210 feet, but since the above results were tabulated the length of face has been increased to about 300 feet, and the average daily output increased to between 80 and 90 tons per shift.

COST PER TON OF LABOUR ON NO. 1 CONVEYOR FACE AT KIMBLESWORTH COLLIERY.[1]

No. of Men.	Description.	Duties.	Cost per Ton. I. 899 Tons. s.	d.	II. 705 Tons. s.	d.
1	Cutter-man	Drives coal-cutter	0	0·96	0	1·23
2	Cleaners-out	Clean cuttings out of cut coal, and cast them back	0	1·49	0	1·89
1	Timberman	Sets timber after machine, etc.	0	0·74	0	0 95
1	Shot-firer	Drills holes in cut coal, and charges them	0	0·64	0	0·82
6	Coal-fillers	Fill coal away cut by machine	0	5·41	0	6·90
1	Deputy	Charge in day-shift, timbering and keeping work away	0	0·96	0	1·22
1	Supervisor	Charge in night-shift, moving conveyor, drawing timber and stoneman	0	1·17	0	1·66
2	Conveyor-heads	Attending to filling of tubs and braking the conveyor	0	0·88	0	1·12
7	Stonemen	Working canches in main-and-tail gates, and putting in packs	0	3·91	0	4·98
4	Conveyor-shifters	Move timber, and shift the conveyor up to face	0	2·28	0	2·91
3	Timber-drawers	Set timber, and draw back timber	0	2·39	0	3·05
6	Hewers	Driving main-and-tail gates, and making stables	0	4·74	...	
1	Putter	Putting coals from hewers	0	0·30	...	
1	Mechanic	. . . .	0	1·06	0	1·35
Depreciation			0	1·18	0	1·50
Cost into driver's set			2	4·11	2	5·58

[1] "The Conveyor System for Filling at the Coal Face," by W. C. Blackett and R. G. Ware, *Trans. Inst. M.E.*, vol. xxviii., 1905.

At the Kimblesworth Colliery, Durham, a motor-driven coal conveyor has been at work for some time in a $2\frac{1}{2}$ feet seam. The coal is undercut by a Diamond coal-cutter which "holes" at floor-level to a depth of $4\frac{1}{2}$ feet. The length of face is about 250 feet.

The table on the preceding page gives the calculated cost per ton for a fortnight's work at this colliery, the costs in column I. being calculated on the coals got from conveyors and from the hewers in the gates and stables, and those in column II. from the coals delivered by the conveyor only.

CHAPTER XI

TYPICAL COLLIERY ELECTRICAL INSTALLATIONS

Continuous current plants—Electric-power plant at Bradford Colliery—Alternating current installations—Three-phase plant at Cambrian Collieries.

Continuous Current Plants

Although it cannot be denied that the three-phase alternating current system possesses, in many respects, considerable advantages over continuous current, yet, owing probably to its greater simplicity and also to the fact that it had gained a firm foothold in colliery work ere the utility of alternating current had been satisfactorily demonstrated, the direct current system enjoys a very widespread application in modern mining.

In view of this, it will result in much profit if we first devote our attention to a typical continuous current installation.

The plant which, under this heading, we propose to describe, and which may be taken to represent all that is best and most up-to-date in continuous current work, is the one erected by Messrs. J. H. Holmes & Co., of Newcastle-on-Tyne, at the Bradford Colliery Company's works near Manchester.

Electric-Power Plant at Bradford Colliery [1]

In this plant two steam-engines, $14\frac{1}{2}$ inches and 24 inches by 10 inches stroke, each capable of developing 195 B.H.P. with 90 lbs. steam pressure, and of sustaining an overload of 25 per cent. for two or three hours when required, are coupled direct to two Johnstone-Lundell six-pole traction generators designed for an output of 130 kilowatts each, at 525 volts, at 380 R.P.M., and for a 25 per cent. overload for two or three hours, with fixity of brushes and sparkless commutation. In addition, there are other two steam generators, one of which is also used for power, and the fourth is used for surface lighting.

Three of the engines are of Messrs. Browett, Lindley & Co.'s

[1] Extract from the *Electrical Magazine*, March 1907.

self-lubricating enclosed compound vertical type, the fourth being an open type vertical engine.

The Generators are fitted with split laminated pole pieces, having an extended pole tip on one side, so proportioned that this half of the magnet core is saturated by the shunt turns alone; as the load increases, the compound winding quickly changes the induction density in the other half of the pole, at which point a strong field is required to obtain sparkless commutation at all loads.

The armatures are slot-wound, and the commutators are of ample diameter, composed of hard-drawn copper with mica insulation, of such dimensions as to ensure adequate capacity to carry the maximum current without excessive heating. The brush holders are carried from substantial split rings, with adjusting screw attached to the yoke ring. The bearings are self-adjusting and self-oiling.

The largest dynamo absorbs 500 B.H.P., and gives out 340 kilowatts with a voltage of 525 at 250 R.P.M. The engine to which this is directly coupled is totally enclosed, with forced lubrication, and has three cylinders, one high-pressure, 24 inches diameter, and two low-pressure, 27 inches diameter, with 12 inches stroke; at 90 lbs. pressure it runs as a compound engine.

The generator has eight poles of the Johnstone-Lundell split pole type, as previously described. The armature is 52 inches diameter and $11\frac{1}{4}$ inches long, with a thoroughly well ventilated core, so that the temperature rise on a six hours' test was only 40° F.

The Surface Lighting Plant consists of a motor generator and a Castle two-pole dynamo with drum armature wound with laminated conductors. This latter has an output of 15 kilowatts at 230 volts, 225 revolutions, and is coupled to an open engine having a single cylinder $9\frac{1}{2}$ inches diameter and 9 inches stroke, with automatic expansion governor working at 90 lbs. steam pressure.

The Motor Generator is used to transform the high volts used for power down to the 230 volts necessary for the lamps used on the surface. The motor absorbs 70 B.H.P. at 525 volts, driving the generator, which has an output of 47 kilowatts at 230 volts, the combination running at 500 revolutions. Both machines are of the Castle six-pole type, are of the same size, and designed for running continuously with a low temperature rise. The motor is shunt-wound and of the totally enclosed type, and the generator compound-wound.

The Main Switchboard in the engine-house is very complete, and is composed of enamelled slate panels with separators between the positive and negative poles. The main generator panels are fitted with dead-beat ammeters, automatic circuit-breakers, patent quick break chopper switches, and the necessary fuses. Dead-beat voltmeters are fitted at the top of the board, together with a clock, these being mounted in an ornamental pediment. The dynamo shunt-

regulating switches and resistances are arranged that the resistance coils are coupled direct to the switch contacts at the back of the panels, so that no connecting wires are necessary for joining up the switches to the resistances. The circuit panels are fitted with double-pole chopper switches and fuses, there being a dead-beat ammeter provided for each circuit. The whole board is mounted in a moulded frame, the total length of the board being over 20 feet.

The Cables are 61 by 0·090. All the cables are armoured and lead-covered, of the 2500 megohms quality. The cables at the pit bottom are so arranged that, in the event of one pair of cables breaking down, they would be cut out and the supply taken from one of three sets until the repairs were made good, thus obviating the risk of a stoppage to any part of the workings.

There are four hauling sets, three for endless rope and one for tail rope. Each of the endless rope sets is driven by a 35 B.H.P. enclosed Castle six-pole motor, compound-wound, and designed to run at 300 revolutions per minute on a 500-volt circuit. The armatures are slot-wound, with formed coils, so arranged as to obtain the maximum mechanical strength combined with the highest electrical efficiency. The motors are fixed to separate bedplates, each having three bearings of ample surface, fitted with ring lubrication and oil gauges. Grooved pulleys, 20 inches in diameter, are fitted to take twelve $\frac{3}{4}$-inch cotton ropes.

The hauling gear constructed for endless rope haulage is mounted on an H section frame, fitted with angle and knee pieces at the corners, in convenient lengths for taking underground and fitting up, and consists of first motion shaft driving the winding drum through double helical gearing. The first motion shaft is fitted with a 6 feet 8 inches diameter split pulley for twelve $\frac{3}{4}$-inch ropes, and runs at 110 R.P.M.; from this, the power is transmitted by double helical gear to the hauling drum. The latter is 4 feet 9 inches in diameter by 8 inches face, runs at 16·5 R.P.M., and is fitted with cast-iron concave laggings, which are made detachable; these can be quickly removed and renewed on showing any signs of wear. Attached to the side of the drum is the brake sheave, 5 feet in diameter by 7 inches face; the strap is of steel, fitted with oak blocks. The brake is applied or released by a slow motion screw fixed to the lever arm. The hand wheel on the screw is fixed near the starting switch, thus enabling the man in charge to start or stop with promptitude.

One of the hauling sets has two drums, operated by clutches, working two brows terminating at one point at the top of the brows.

One of the endless rope gears has an extended bedplate on which is temporarily fixed a tail rope drum, 3 feet diameter, and driven by a Ewart's chain from the first motion or rope-driven shaft. This was used for driving a new brow downhill, during which work the endless rope drum was put out of gear. The new brow is just

completed, the tail rope drum put out of gear, and the endless rope put to work.

The endless hauling ropes are 2400, 1100, 1000, and 700 yards long, and can be varied to travel at from one and a half to three miles per hour. To run each rope light takes 22 per cent. of the normal full load.

These sets have been running for over five years, during which time they have been worked to their maximum capacity practically day and night without breakdown or stoppage.

The Starting Switches are specially designed to give slow and steady starting, and to permit of running from half to full speed. Each starting switch has two slates. On the short upper slate is fixed a single pole switch, mechanically closed on the first turn of the slow motion screw, and afterwards magnetically held on. On stopping, or failure of supply, this switch opens, and prevents any damage arising from careless handling by starting the motor with all resistance cut out. To close the switch, all the resistance must be run in, and the operation repeated. On the lower slate are fitted the bus bar and the resistance section contacts. On the slow motion screw a crosshead is carried, to which are fixed two sliding connectors or contacts connecting the bus bar with the resistance sections.

The tail rope hauling set is similar to the larger set, except as regards the drum, which is designed to hold about 1500 yards of $\frac{5}{8}$-inch diameter steel rope, and is driven by a 20 B.H.P. enclosed six-pole motor, with rope pulleys, etc., as previously described.

There are two sets of electrically driven pumps. The high duty pump is of the treble ram type, with rams 6 inches diameter by 9 inches stroke, and when running at 40 R.P.M. delivers 5500 gallons per hour against a vertical head of 1680 feet. The motor is of the enclosed six-pole type, capable of developing 75 B.H.P. at 350 R.P.M. at 500 volts. The power is transmitted through two reductions, the first being twelve $\frac{3}{4}$-inch ropes, as in the haulage, and the second double helical gear. Owing to the liability which existed of this motor being flooded, it was raised to a higher level, and ropes were substituted for the original spur gearing first reduction. Starting and regulating switches and circuit-breakers are fixed close to the motor. The pumps are started up against the full column of water, as the latter is very rarely run off.

The low duty pump is of the same type, but fitted with rams 8 inches by 9 inches stroke, and at 44 R.P.M. it delivers 12,000 gallons per hour against a head of 470 feet. This pump is driven by a 85 B.H.P. enclosed six-pole motor, running at 300 R.P.M. at 500 volts, complete with gearing similar to the above, excepting that the motor is mounted on an extended bedplate, the first reduction being machine-cut steel spur and pinion wheels.

All the larger haulage and pump motors are duplicates, and inter-

changeable, necessitating a minimum of spare parts being kept for emergencies.

The workshop tools, including circular saw, planing, morticing, and other woodworking machines, are driven by a 15 H.P. motor running at 600 R.P.M.

A 10 H.P. motor of the same type drives creepers underground for conveying loaded wagons from one level to another, and a second motor of this size ran for three and a half years driving a "Sirocco" blowing fan, ventilating a large shaft during the process of sinking to the great depth of 2804 feet. During the whole of this time the motor was started at six o'clock each Sunday night, and ran continuously until the following Saturday night at six o'clock. No trouble of any description or stoppage, beyond that mentioned, occurred to the motor throughout this period. It is now driving creepers on the surface for elevating wagons to a higher level.

Two motors, each of 80 B.H.P., are driving mechanical screens, picking belts, slack elevators, etc.

A small, but at the same time an important, item in the installation is a portable air-compressor, driven by one of Messrs. Holmes & Co.'s Lundell patent motors, for cleaning the dynamos and motors.

Alternating Current Installations

As has already been remarked, alternating current for transmitting purposes is in many respects superior to continuous current. With alternating current the power may be generated at pressures varying from 1000 to 5000 volts, transmitted down the shaft at that voltage, and there transformed by means of static transformers down to a voltage suited to the different motors. The economy in the price of conductors as the result of this high-pressure transmission and distribution is very considerable, and coupling with this consideration the fact that non-sparking, non-commutator motors can be used, it is not surprising that the alternating current system is usurping the primary place for colliery work generally.

Of the alternating current system, three-phase seems to be the form almost universally adopted for colliery power generation.

A typical example of a three-phase installation is afforded us in the power plant recently erected at the Cambrian Collieries, South Wales.[1]

For generating the steam supply, there are four Lancashire boilers, each 30 feet long and 9 feet in diameter, and working at a blow-off pressure of 160 lbs. per square inch.

Each boiler is equipped with a Sudgen superheater to give 150° Fahr. superheat when the boiler is evaporating 9000 lbs. of water per hour. A Green's economiser is also employed, which

[1] Extract from the *Electrician*, 5th July 1907.

raises the temperature of the feed water from 60° to 200° Fahr. when the four boilers are evaporating at the rate of 30,000 lbs. per hour. A Siemens three-phase 3 B.H.P. 400 volt motor is provided for driving the economiser scraping gear.

The feed water is softened in a water-softening plant, from whence it is supplied to the boilers by two Weir vertical single-cylinder double-acting feed pumps, each capable of supplying 3000 gallons of water per hour, and by one Korting injector for a duty of 1250 gallons per hour.

As shown in the general plan of the power station (Fig. 140), the boilers are erected at the side of the engine-house.

As shown in the general arrangement of the engine-room, space is provided for three generating sets. At present, the generating plant consists of two Siemens-Belliss & Morcom sets. These two sets are alike in all respects, each consisting of a Belliss & Morcom vertical steam-engine direct-coupled to a Siemens 1000 K.V.A. three-phase 2200 volt 25 cycle alternator. The normal speed of the set is 250 revolutions per minute, and it was found from tests on one of the sets that the speed rose momentarily to 263 revolutions per minute, settling to 254 revolutions per minute, when full load was switched off, while it dropped momentarily to 240 revolutions per minute, settling to 250 revolutions per minute, when full load was switched on.

The engine speed can be varied while the engine is running from 240 to 260 revolutions per minute.

Steam consumption tests were carried out at the makers' works with the following results:—

Steam consumed per kilowatt-hour at full load, 17·3 lbs. of steam at a pressage of 155 lbs. per square inch, and a temperature at the stop valve of 472° Fahr., the vacuum being 25·9 inches of mercury. At half load, the steam consumption was found to amount to 18·6 lbs. of steam at a pressure of 163 lbs., a temperature of 461° Fahr., and a vacuum of 26 inches. The internal diameters of the high-pressure, intermediate, and low-pressure cylinders are $18\frac{1}{2}$ inches, 27 inches, and 40 inches respectively, the stroke being 20 inches. The cylinders are lagged with non-conducting material covered with planished steel sheet. The engine is capable of carrying an overload of 25 per cent. for two hours, and momentary overloads of 50 per cent. When running non-condensing, the engine is capable of developing 680 kilowatts. All working parts are lubricated under pressure, oil being supplied by a valveless pump worked direct from the crank shaft. The flywheel weighs $12\frac{1}{2}$ tons.

The Siemens three-phase 2000–2200 volt alternators are of the rotating field type, the phases being star-connected. They have a continuous rating of 750 kilowatts at a power factor of 0·75, and are capable of dealing with the same overloads as the engines. It

was specified that after a six hours' run at 750 kilowatts and unity power factor, no accessible part of the machine, with the exception

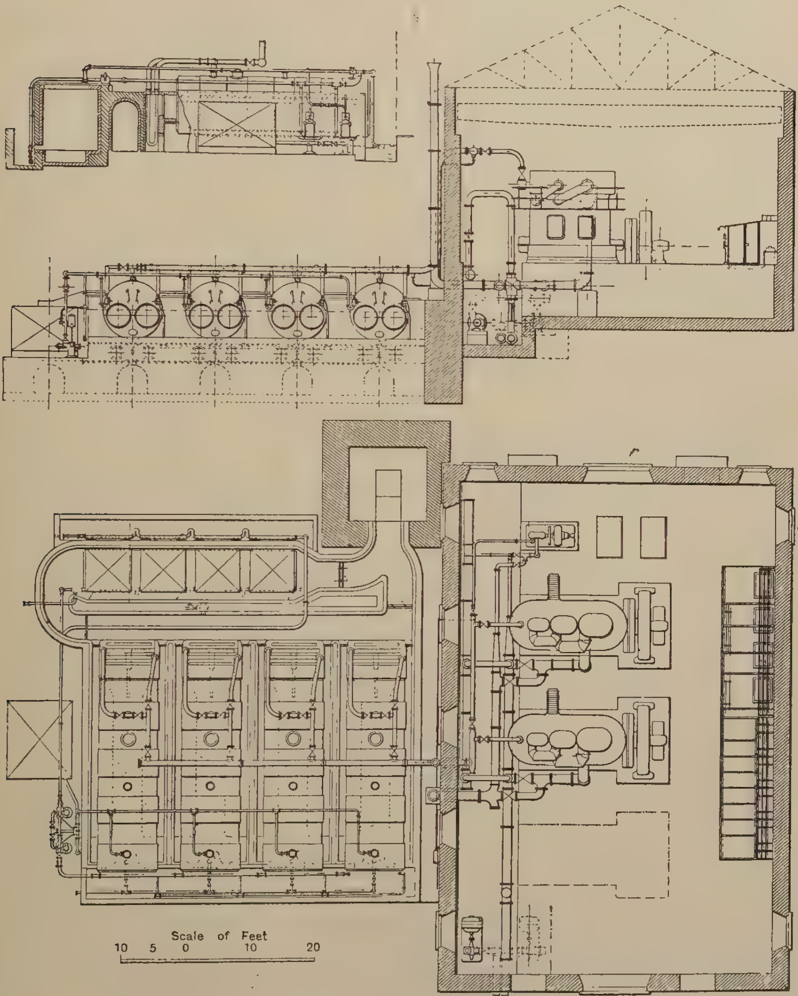


FIG. 140.—Plan of power station at Cambrian Colliery.

of the stator iron, was to have a temperature rise of more than 35° C. above the surrounding air as measured by thermometer; the tempera-

ture rise in the stator iron was not to exceed 45° C. The temperature rises observed in the tests were $38\frac{1}{2}°$ C. for the stator iron, and 22°·8 C. for the rotor winding. The machine is wound to have a wave form as nearly sinusoidal as possible. With full non-inductive load thrown off, the percentage rise of voltage was specified not to exceed 6 per cent. at constant speed and excitation. In the tests, as a matter of fact, the alternator voltage only rose from 2210 to 2310, *i.e.* about $4\frac{1}{2}$ per cent., despite the increase in the speed of the set. At a power factor of 0·75 the rise does not exceed 18 per cent.

The rotor of each alternator is directly bolted to the engine flywheel, and the energy stored in the rotor field magnets and engine flywheel amounts to 2000 foot-tons at normal speed. The poles are circular in section, and the pole shoes are laminated. The stator is of cast iron, and of such a design as to combine great stiffness with light weight.

The exciting current at 110 volts is fed to the rotating field by copper gauze brushes impregnated with carbon, which are pressed against the two slip rings by brush holders of the lever type, the tension on the brushes being maintained by helical springs. The shaft runs in ring lubricated bearings of ample size.

The two main engines exhaust into ejector condensers, supplied by Messrs. Korting Bros., and placed in the basement underneath the floor, each capable of dealing with 13,000 lbs. of steam per hour, and producing a vacuum of 26 inches of mercury. The condensers discharge into a tank 20 feet by 10 feet by 6 feet, built up of cast-iron plates.

The centrifugal pump for pumping the condenser discharge back into the pond is capable of delivering 50,000 gallons of water per hour against a head of 80 feet when rotating at 1450 revolutions per minute. It is directly driven at the speed mentioned by a Siemens three-phase squirrel-cage ventilated type 40 horse-power motor, which is fed with current at 25 cycles per second from the 400-volt alternating supply.

The switchboard is made up of three alternator panels, of which one is blank, and six feeder panels, of which three have been fitted up with apparatus so far. Each of the two motor-generators is controlled from one continuous current and one alternating current panel. There is also a lighting panel in the centre of the board, an exciter panel, and three transformer panels, and a number of blank panels are provided for future extensions. The main panels facing the engine room are of white marble, and supported on an iron framework.

The electric power developed by the two 1000 K.V.A. generating sets now working is principally used for operating three-phase induction motors for a great variety of purposes in all parts of the mine. There are at present some 21 induction motors in use, ranging in size

from 220 to 3 horse-power, the total horse-power of motors being 1890. Motors on the surface are supplied with three-phase current at low tension, the current being transformed for this purpose by static transformers from 2200 volts, the voltage produced by the alternators in the power house, to 400 volts. The bulk of the supply, however, is conveyed by cables at a voltage of from 2000 to 2200 volts down the pits, and distributed to the various motors at this pressure. Continuous current for exciting the main alternators and for lighting and working the original motors is supplied at a pressure of 110 volts by a 36 kilowatt steam-driven dynamo, or by two 70 kilowatt motor-generators taken over from the original plant.

Only part of the electric energy available is utilised at present, but as electric motors are being constantly added, the power house will be fully loaded at no distant date. Space has been left in the engine-house for the erection of a third generating set, when this becomes necessary, and ample provision has been made in the design of the switchboard, boiler, and condenser plant to carry out this extension with a minimum amount of expense or alteration.

The whole of the electrical plant at this colliery has been erected by the firm of Messrs. Siemens Bros., London.

CHAPTER XII

MISCELLANEOUS APPLICATIONS OF THE ELECTRIC CURRENT

Electric Fans—Quick-running type—Slow-running type—Blasting by electricity—Advantages—High-tension system—Low-tension system—Series and parallel systems of firing shots—Electric detonators—Firing the shot—Primary battery exploders—Magneto exploders—Dynamo-electric exploders—Firing shots from power or lighting mains—Precautions to take—Electric safety lamps—The Sussman lamp—The Shamrock lamp—The Headland lamp—Electric lighting and re-lighting of safety lamps—Telephones—Motor-driven air-compressors—Electric signalling—Magnetic separation of minerals—Electrical equipment of colliery workshops—Electric welding—The Arc system—The Thomson system.

Electric Fans

The substitution of electric motors for steam-engines for actuating colliery fans, especially where generating plant for general purposes has already been installed, has much to recommend it.

The efficiency of the modern electric motor is high, and if reasonable care is exercised in working and in keeping it in good condition it may run for years without causing any trouble whatever.

Again, the motor may be relied upon to run always at practically constant speed, thus ensuring uniformity and steadiness in the ventilation. The motor also takes up less room than the steam-engine, and is more suitable for operating quick-running fans. It is in the working of underground fans, however, that the electric motor shows to most advantage.

The transmission of electrical energy underground can be effected more efficiently and economically than the conveyance of steam pressure, in which there must always be considerable loss from condensation and other causes.

For ventilating narrow drivages, stone mines, cross-measure drifts, and similar undertakings, the electric fan possesses conspicuous advantages.

Such workings have frequently to be ventilated by small auxiliary fans, it being in many instances impracticable or undesirable to carry the main ventilating current into the drivages, and for such fans the electric current is *par excellence* the ideal motive-power.

The fans most suitable for operation by electric motors are those of the small quick-running type, such as the "Sirocco," the Schiele, and the Capell fans.

In the quick-running type the weight of the structure to be moved is comparatively small, and the speed may be anything from 250 to 1000 revolutions per minute; little or no reducing gear is necessary between the motor shaft and the fan shaft, many fans being coupled direct to the armature spindle.

Large slow-running fans such as the Guibal, the Waddle, the Leeds, etc., may also be electrically driven by belt-drive from the motor shaft.

Probably the most popular electric fan is the "Sirocco," hundreds of which have been installed in recent years in British collieries, both above and below ground. This fan is of small construction, and runs at a high speed, and its efficiency as a ventilator is very high.

At the Hulton Colliery, Chequerbent, a motor-driven "Sirocco" fan was recently installed. The fan is situated at the top of the upcast shaft, and is 70 inches in diameter. It has a capacity of 150,000 cubic feet of air per minute, with a water gauge of 3 inches, and running at a speed of 325 revolutions per minute. The fan is rope-driven from a three-phase current motor, and gives every satisfaction. As showing the adaptability of the motor-driven fan to special requirements, the following account of the employment of three fans, each working independently of the other, may prove interesting.

At a large Lancashire colliery three seams of coal are being worked from the same pair of shafts at depths of 150, 300, and 400 yards respectively. The seams are each ventilated by a separate air supply, and a separate motor-driven fan propels the air current in each case.

The fans are situated in "cut throughs" between the upcast and downcast shafts, each fan being situated at or near the level of the seam in which it produces ventilation. The ventilation of each seam is entirely isolate. The air is made to course from the downcast shaft, through the workings of each seam, then through the fans and out into the upcast shaft. The fans are of the "Sirocco" single-inlet type. Two of the fans are of 45 inches diameter, and are rope-driven from 45 horse-power three-phase motors, and run at 380 revolutions per minute. The third fan is 30 inches in diameter, runs at 580 revolutions per minute, and is rope-driven from a 30 horse-power motor.

Electric Blasting

Shot-firing by electricity is now very frequently adopted in modern mining. Its advantages over the ordinary methods of squib and safety fuse ignition of the explosive are numerous, and indeed,

in many instances, it is the only method which can be said to be absolutely reliable and effective.

Principal amongst the many advantages claimed for electric blasting are the following:—

1. Complete safety in firing shots in any situation.
2. Suitability for firing shots in groups simultaneously.
3. Absence of "miss-shots."

Blasting operations in sinking shafts or stone drifts are very frequently carried out by the electric method, and in dry and dusty or fiery mines it is compulsory to fire all shots by efficient electrical apparatus. As regards the cost of shot-firing by electricity, it has been found that for blasting in gaseous mines it is the cheapest method that can be adopted.

The methods of electric blasting may be classified under the following four heads:—

1. Low-tension system.
2. High-tension system.
3. Firing in series.
4. Firing in parallel.

1. *Low-tension System.*—The low-tension method of shot-firing by electricity, as is illustrated in Fig. 141, consists in passing a current

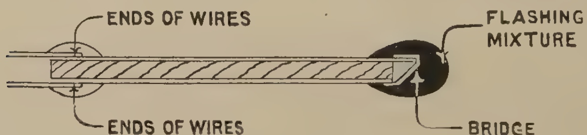


FIG. 141.—Low-tension system.

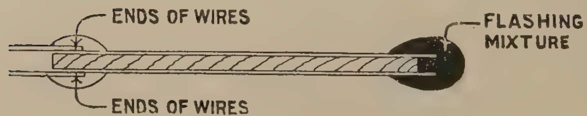


FIG. 142.—High-tension system.

of electricity at a low voltage through wires embedded in the flashing material of the charge. The ends of the two wires, where they terminate, are connected together by means of a small platinum bridge. This platinum bridge offers a great resistance to the passage of the current, and, in consequence, great heat is generated, and this heat is sufficient for the ignition of the flashing mixture. This sets off the detonator, which in turn explodes the charge.

2. *High-tension System.*—In the high-tension system the only

difference from the low-tension is that the platinum bridge is wanting, and, instead, a very short air-gap is allowed to exist between the ends of the two wires embedded in the flashing mixture (Fig. 142). Current at a high voltage is used, and the electricity jumps or arcs across the air-gap from the positive wire to the negative. A flash is thus produced which ignites the flashing mixture, and the charge is fired as before.

3. *Firing in Series.*—In this method the charges are so arranged that the current passes from the positive wire of the circuit, through each of the fuses of the different charges in turn, the last fuse of the entire volley being connected to the negative wire. The same current

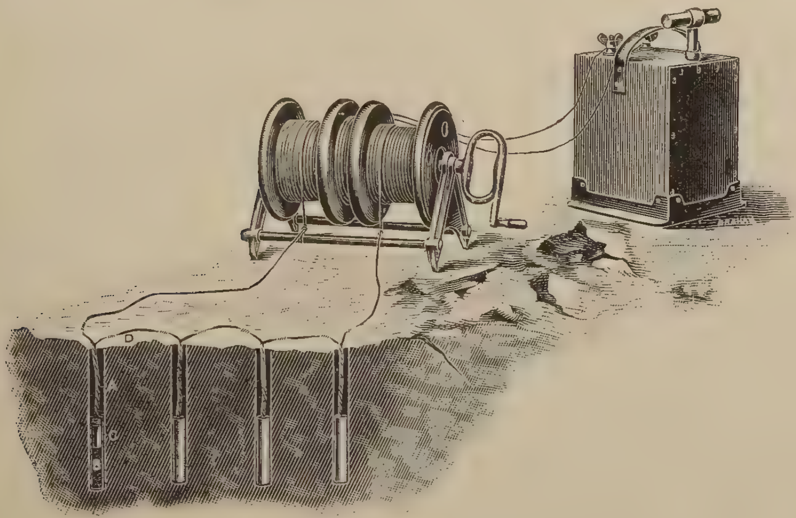


FIG. 143.—Arrangement of shots in series. A, shot hole ; B, charge ; C, primer cartridge, containing detonator ; D, connecting wire between charges.

thus passes through the whole of the fuses. Fig. 143 shows a group of charges arranged for firing in series.

4. *Firing in Parallel.*—In this method each detonator is connected directly to the positive and negative wires, so that a portion of the total current goes into each fuse separately.

The result in either of the above cases is exactly the same. The whole series of shots will be fired simultaneously. The series arrangement is more easily made up than the parallel system ; more wire is also required in the latter method, and whereas the series system takes a big voltage but little current, the parallel method requires a big current and a low voltage.

It will be noticed that the above remarks apply principally to shots fired in groups, this being the usual arrangement in operations where much blasting has to be done. Where shots are fired singly on either the low-tension system or the high-tension system, the shot-firing cables and the wires attached to the detonator form a single complete electric circuit.

For firing a number of shots simultaneously, the series system is the best and is the method generally adopted, and low-tension fuses are usually employed.

Electric Detonators

The detonators which are used in exploding the charge in electric blasting are manufactured in a number of varieties. The Nobel's Explosives Company turn out what is probably the most reliable electric detonator on the market. The leading features of this detonator are shown in Fig. 144. The wires are soldered to the fuse head, on which is the flashing mixture; the fuse head is fixed inside a paper tube, and this is crimped into the copper tube of a detonator, the top of which, for further protection, is covered with pitch.

Firing the Shot

Firing by electricity is a simple though delicate operation. One of the cartridges of explosive forming the charge is opened, and a hole made in it with a small stick. In this hole the electric detonator is buried, as shown in Fig. 145. The open end of the cartridge and the detonator is then secured with a piece of string. This cartridge is termed the "primer" cartridge, and is inserted in the shot hole *behind the rest of the charge.* The "primer" cartridge should be inserted into the hole with the detonator leading. This arrangement prevents the detonator being struck by the tamping rod during stemming. After tamping has been done, the projecting ends of the wires are connected to the bared strands of the shot-firing cable. The shot-firer then retires to a safe distance and fires the charge. Care should be taken *not* to connect the firing cable to the exploder until everything is ready for the charge being fired.

Exploders

The apparatus for providing current for firing the charges are termed exploders. Exploders may be divided into the following three separate classes :—

1. Primary battery exploders.
2. Magneto exploders.
3. Dynamo-electric exploders.

1. *Primary Battery Exploders* consist of chemical cells or batteries,

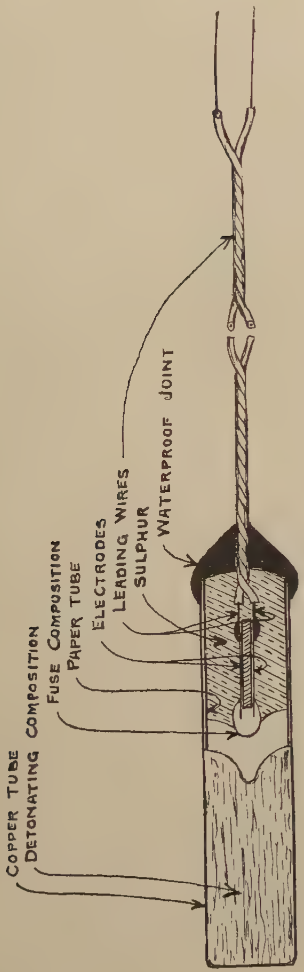


Fig. 144.—Nobel's electric detonator.

Fig. 145.—Insertion of electric detonator into cartridge.

such as the Leclanché, or Carporous (see Chapter I.). Dry batteries are also sometimes employed.

2. *Magneto Exploders* consist of an armature which is revolved

between the poles of one or more permanent horseshoe magnets. When the armature is revolved an electric current is produced. A machine of this type is shown diagrammatically in Fig. 146. The

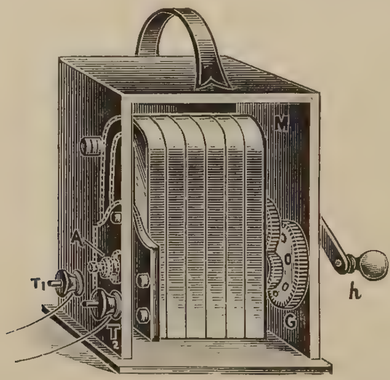


FIG. 146.—Magneto exploder. M, horse-shoe magnets; G, gearing; *h*, handle; A, end of armature spindle; T_1 T_2, terminals.

handle is turned at a good speed, and then, by means of a button switch, the circuit is completed and the charges exploded.

3. *Dynamo-electric Exploders* generate current after the manner of the ordinary continuous current dynamo; the armature revolving in a strong magnetic field generates a powerful voltage. This type of exploder is very suitable for shaft work, and in driving large "mines" and drifts.

Shot-firing from Power or Lighting Mains

This is permissible only in sinking shafts or stone drifts. For this purpose a special firing plug or switch is used. This plug or switch is kept in a fixed locked box, and should only be accessible to the authorised shot-firer.

Fig. 147 illustrates a shot-firing arrangement designed by Messrs. John Davis & Son, Derby, employed in blasting by current taken from either lighting or power mains. Each main is provided with a switch, a tumbler switch being inserted on the positive side and a "press-down" firing key on the negative. From the tumbler switch the current passes to the fuse, thence to the charges to be fired, and then back to the negative main by way of the firing key. In firing, the tumbler switch is first put in and then the firing key depressed. An incandescent lamp is placed in circuit, as shown, when it is desired to test the apparatus. If the apparatus is in good working order the lamp will light up.

The apparatus is enclosed in a strong case, which is kept locked.

Precautions to take in firing shots by electricity are :—

1. See that all joints and connections are properly made.
2. Scrape ends of wires with a knife before connecting up.
3. Make sure that the connection of the firing cable to the exploder is the *last* thing to be done before firing.
4. Disconnect firing cable immediately the charge has been fired.
5. Keep the hands clear of exploder terminals whilst firing.
6. Have the handle of the exploder revolving at maximum speed when pressing the firing knob or switch.

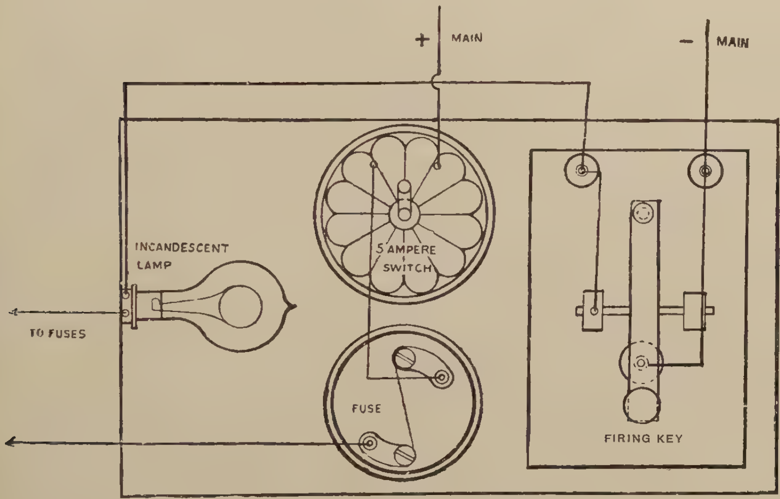


Fig. 147.—Shot-firing arrangement.

Electric Safety Lamps

Electric safety lamps are sometimes used in place of the ordinary form of safety lamp.

The advantages are :—

1. Greater lighting power.
2. Consequent greater safety in working.
3. Little or no danger of igniting gas, the air being entirely excluded from the glowing filament, and, if the glass bulb is broken, the light is instantaneously extinguished.
4. It can be used with greater freedom than the ordinary safety lamp, which has to be very carefully handled in an explosive mixture.

Disadvantages:—

1. Slightly heavier than the ordinary form of safety lamp.

2. The presence of gas cannot be detected by it, necessitating the carrying of an oil safety lamp as well, in order to be able to test for gas when necessary. (This is probably the greatest objection to the use of the electric safety lamp in fiery mines.)

3. Electric safety lamps cost more, and are more expensive to maintain, than the ordinary form.

An electric safety lamp consists of a battery, either primary or secondary (the latter being usually employed), and an incandescent lamp.

The voltage employed depends upon the number of cells in the battery. If one cell is used, the voltage will be from 1·5 to 1·8; and if two cells are employed, from 3 to 3·6 volts will be obtained. There are a number of safety lamps on the market, but those most commonly used are the Sussman lamp, the Shamrock lamp, and the Headland lamp.

The Sussman Lamp.—In this lamp an accumulator of the Faure or pasted type supplies current to the incandescent lamp.

The battery forms the lower portion of the lamp, and the lamp bulb forms the top part. There is a cage or shield round the bulb to protect it from injury.

The lamp weighs from 3 to 4 lbs., and stands about 8 inches high.

The battery is sufficient to keep the lamp lighted for about 10 hours continuous.

The Shamrock Lamp.—This lamp is of German make. It consists of a two-cell storage battery giving a working voltage of about 3·75 volts, and an incandescent lamp. The lamp consumes from 0·5 to 0·6 of an ampere, and the battery is able to keep the lamp burning at an average brilliance for from 10 to 12 hours. The life of the incandescent lamp used runs from 100 to about 140 hours. A small lever switch, contained in a switch box, is provided for the switching in and out of the light.

The Headland Lamp.—In this lamp a special type of accumulator known as the Headland battery is used. This cell is designed on the Faure or pasted principle. It consists of a grid formed by a series of bars being built up alongside each other. Each of these bars is filled with a paste. The lamp gives a good light, and will burn for about 10 to 12 hours.

Electric Lighting of Safety Lamps

The application of electricity to the lighting and re-lighting of the ordinary oil safety lamp is now in very general use.

There are two distincts methods of lighting in use, namely, the high-tension method and the low-tension.

In the high-tension method, current at a high voltage is used. In the lamp to be lighted is an insulated conductor which runs through the oil-vessel, and terminates in a hook-like fashion over the wick tube. The insulated conductor is attached to the positive wire coming from an accumulator battery with an induction coil in circuit, and the negative wire is connected to the body of the lamp. On current being passed through this circuit a spark occurs between the pointed end of the insulated conductor and the wick tube, the current returning through the lamp body to the negative wire. This sparking is sufficient to light the wick of the lamp.

In the low-tension method, current at a low voltage is used.

Fig. 148 shows this method in operation. At the side of the wick

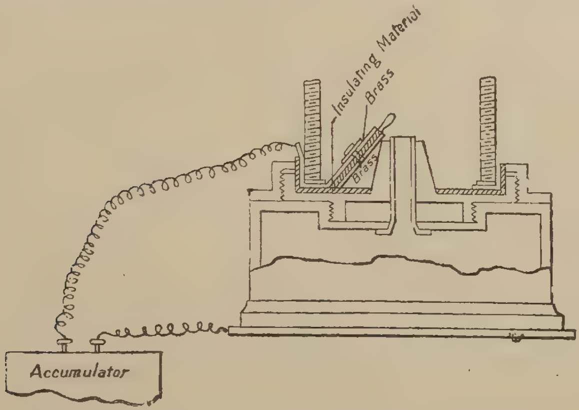


Fig. 148.—Low-tension method of lighting safety lamps.

tube is a brass plate, which is insulated from the frame of the lamp. To this brass plate is connected one end of a loop of platinum wire which overhangs the wick tube. The other end of the platinum loop is connected to the body of the lamp. An accumulator is then connected on its positive side to the brass plate, and on its negative side to the lamp body. On the passing of the current, the platinum loop becomes incandescent, and this incandescence is sufficient to ignite the vapours given off from the wick.

Telephones

The Special Rules for the Installation and Use of Electricity in Mines require that direct telephonic communication shall be provided—

1. Between the surface and the pit bottom or main distributing centre in the pit.

2. Between the generating station and the pit-head.

The telephone, however, is of great service in a mine, for many purposes other than as a means of communication between the generating station and the distributing centres and motor-houses in an electrical installation. Telephones in many instances add materially to the more efficient management of a mine. The management, through their employment, possess a medium through which they may constantly be kept posted up in the progress of the day's work throughout the entire colliery.

Should any mishap occur, intimation can at once be made to the proper quarter, and assistance or advice procured without delay.

The principle underlying the action of the telephone is probably already well known to the average student of mining. Briefly, it consists in the electrical transmission, along a conductor, of the vibrations of a very thin disc of soft iron, and the exact reproduction of those vibrations through the medium of an electro-magnet at the receiving end of the apparatus. The vibrations of the thin iron disc are, of course, produced by the sound waves proceeding from speech, and the vibrations of the disc at the other end, being an exact reproduction of the movements of the disc at the speaking end, an almost perfect reproduction of the speaking voice is the result.

The circuit through which the pulsating currents in the telephonic process are carried may be formed of two metallic conductors, positive and negative, or of one wire and an earth return.

Earth returns are, however, now seldom employed, owing principally to the high resistance offered to the passage of the current, and also because an entire metallic circuit works much more satisfactorily.

Motor-Driven Air-Compressors

Surface air-compressing plant is extremely uneconomical, and compares very unfavourably with electric generation, so far as economy and efficiency are concerned.

The loss of power that necessarily takes place during transmission from the surface to the point of utilisation is enormous, and militates greatly against the possibility of air-compressing plant on the surface holding the position which it has held for so long.

Air-compressing plant, installed underground and driven by electric motors, is, however, coming much into favour, and there is a good deal to be said in support of this arrangement.

The air-compressor can be situated much nearer its work, and the distance over which the power will require to be transmitted thus reduced very considerably.

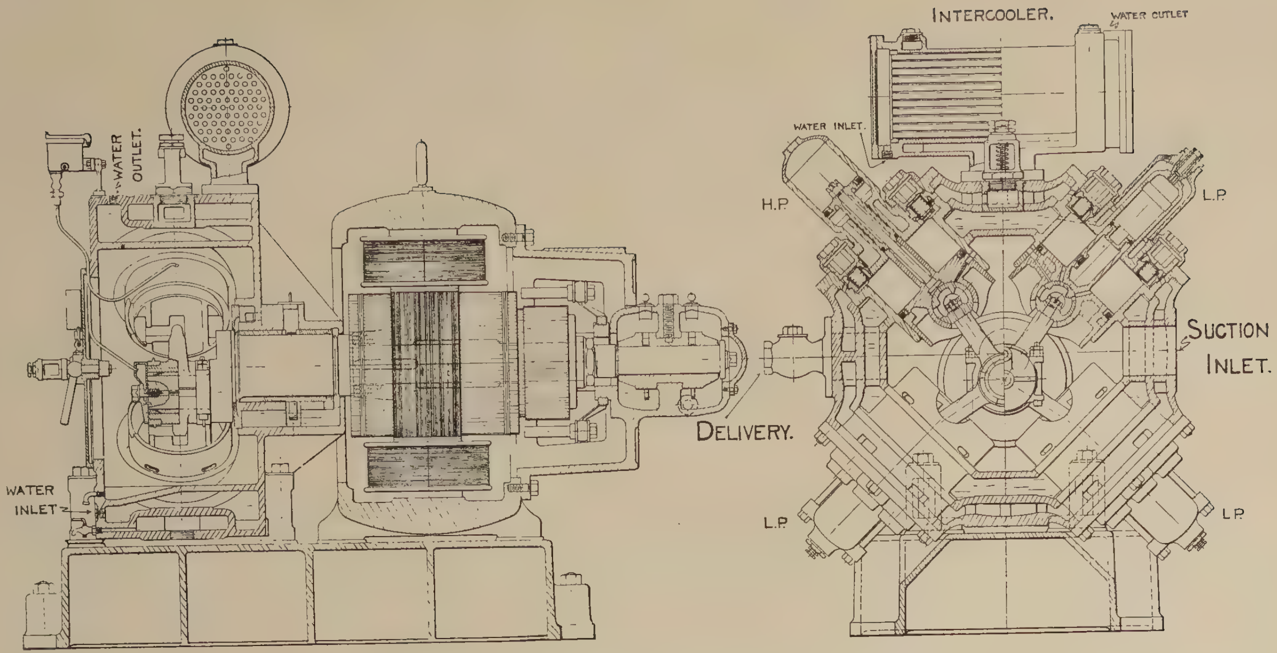


FIG. 149.—Sectional views of Reavell motor-driven air-compressor.

Again, in fiery mines, where it may be doubted that electric motors are absolutely safe, a motor-driven air-compressing plant may be installed, say, at the inbye end of the main intake air-way, and the air-power subsequently utilised throughout the fiery area with perfect safety, for such purposes as coal-cutting, drilling, etc.

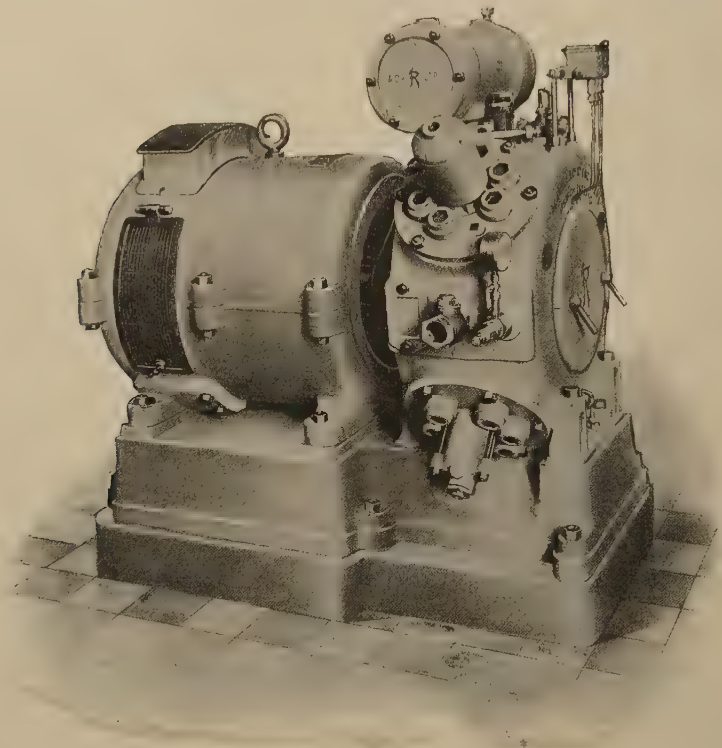


Fig. 150.—Motor-driven air-compressor.

One of the latest and perhaps most noteworthy types of electrically driven air-compressor is that designed by Messrs. Reavell & Co. Ltd., and known as the Reavell compressor.

The Reavell compressor consists of four cylinders arranged radially in a circular-shaped casing, as shown in the sectional illustration, Fig. 149. A trunk piston works in each cylinder, and the four connecting rods are all driven by a common crank pin. Each cylinder forms, as it were, a separate single-acting compressor.

The compressor has no suction valves, air being admitted above each piston by means of a port in the latter, which coincides with a similar port in the top of each connecting rod during the suction stroke; and near the end of this stroke the piston overruns the ports cut through the cylinder wall, thus making direct communication between the cylinder and the inside of the compressor casing, which is arranged to form a suction chamber. Each piston delivers into a common delivery passage, ensuring a practically continuous delivery of air. As each piston compresses only in one direction, the compressor can be run at a relatively high speed, enabling direct coupling to the shaft of a motor to be practicable.

In the type shown in Figs. 149 and 150 the air is compressed in two stages, in the three low-pressure cylinders in the first stage and in the high-pressure cylinder in the second stage. An automatic unloading device is used in the Reavell compressor, consisting of a bye-pass valve, forming a connection between the delivery and suction side of the machine. It is automatically controlled by an air relay, so that when the air pressure reaches the desired limit the bye-pass valve opens, and the delivery chamber is put in communication with the suction side of the compressor. In this way the load is removed from the motor. As soon as the pressure falls to a predetermined limit this valve closes, and the compressor commences to deliver air again.

An automatic stopping and starting switch is employed for the regulation and control of the motor.

The advantages claimed for the Reavell compressor are: (1) Compactness, (2) suitability for electric driving, and (3) high efficiency.

Electric Signalling

Electric signalling has many important advantages over the other forms of signalling used in mines. For long distance signalling, such as from the foot of a dip haulage plane to the engine-house on the surface, it is the ideal system. The signals given, provided a strong enough battery be in use and proper contact is made whilst signalling, are at once clear and distinct. There may be some danger attached to its use in fiery mines, but in the electric Special Rules no higher voltage than 15 volts is allowed on any signalling circuit or part of a circuit; with such a low pressure on the wires, the danger of igniting gas is reduced to a very low minimum. Another great advantage of electric signalling is that, where the wires run along the side of the haulage plane, contact can be made at any point, and a signal given to the engineman in charge to stop or go on as the case might be. In this way many an accident or breakaway of tubs may be averted, or at least rendered less disastrous. The apparatus used consists, in its simplest form, of an

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electric signal bell, a battery of primary cells, and the signalling circuit. The signal bells used are usually of the "single-stroke" type, as illustrated in Fig. 151. The striker or hammer is controlled by an electro-magnet which, when the current is on, actuates a soft-iron armature, which in turn works the hammer or striker of the bell.

The "trembling" form of bell is also sometimes used. It is essential that bells of the "trembling" form, when used in fiery situations, should be enclosed in strong gas-tight casings, as the circuit is made and broken in rapid alternations, a slight spark resulting each time.

The line forming the circuit in electric signalling is generally made with uninsulated galvanised iron wire of from No. 10 to No. 12 S.W.G.

The wire is carried on porcelain insulators fixed at intervals

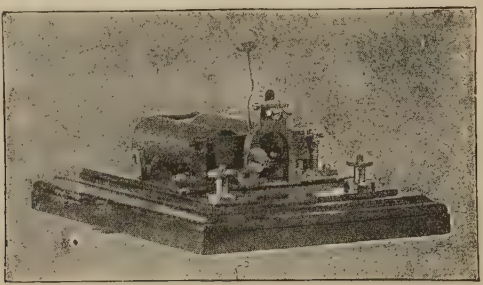


FIG. 151.—Single-stroke electric bell.

down the shaft and along the side of the haulage plane. Sometimes insulated copper conductors are used in the shaft, where a signal does not require to be given. The copper wire used may be any size from No. 16 to No. 22 S.W.G.

A push-button is employed to make contact between the positive and negative conductors, and so complete the circuit and ring the bell. The push-buttons are fitted up at the top and bottom and other important points of the haulage road. However, as the wires are bare, a signal may be given at any point by simply bridging the two wires by means of a knife blade, piece of copper wire, or any other material of good conductivity. Where a number of branches are to be worked in conjunction with the main signalling circuit, relays are sometimes employed. The current from the main battery actuates an electro-magnet in the relay. These magnets complete each local circuit, and as the current from the main battery would not be sufficient to ring the bells, each branch is supplied

with an auxiliary battery to give current sufficient for signalling. Fig. 152 illustrates the method of arranging electric signals.

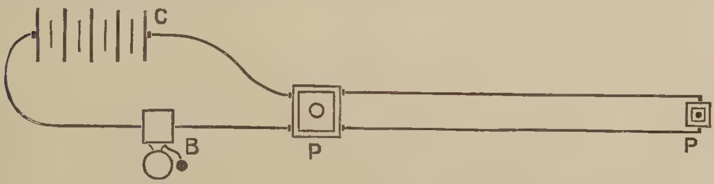


FIG. 152.—Method of arranging electric signals.
C, battery; B, bell; P, push buttons or switches.

THE MAGNETIC SEPARATION OF MINERALS

The attractive power of the magnet has lately been put to practical use in the separation of certain valuable metals from the useless extraneous substances with which these have been associated *in situ*. The magnetic force, possessing a powerful influence over all metallic substances, but having no power whatever over non-metallic material, is able to single out the precious metals coming within the range of its influence, and to collect these entirely free from foreign matter. Iron and steel ores can be most successfully treated in this way, but the process has also given satisfaction in the separation of some of the less potent magnetic ores, such as those of copper, zinc, and tin.

A magnetic separating machine — probably one of the best of its kind—made by the Sandycroft Foundry Company, Chester, is shown in Fig. 153. The machine consists of a powerful horseshoe magnet, between the poles of which rotates a drum. Above this drum is a disc which is made to revolve at a very high speed in a direction at right angles to the direction of motion of the drum. The ore to be separated is run on to the drum. As the drum revolves the material has to pass between the poles of the magnet, and the metallic particles are caught up and thrown on to the disc above, the poles being so arranged that this can be effected. The revolving disc in turn throws the metal into a hopper provided for the purpose. The non-magnetic material, uninfluenced by the magnetic lines of force, passes round with the drum, and is deposited into the dirt hopper.

ELECTRICAL EQUIPMENT OF COLLIERY WORKSHOPS

Colliery workshop tools and appliances may be very advantageously driven by means of electric motors.

In large engineering shops motor driving is largely adopted, and

many economies of time, expenditure, and labour thereby effected, and there is no reason why similar advantages should not be gained in the workshops of collieries by adopting electric driving.

Such tools as circular saws, drilling machines, planing, morticing, and other wood-working machines may be conveniently operated by a single electric motor, the subdivision of the power being effected by means of belting and shafting.

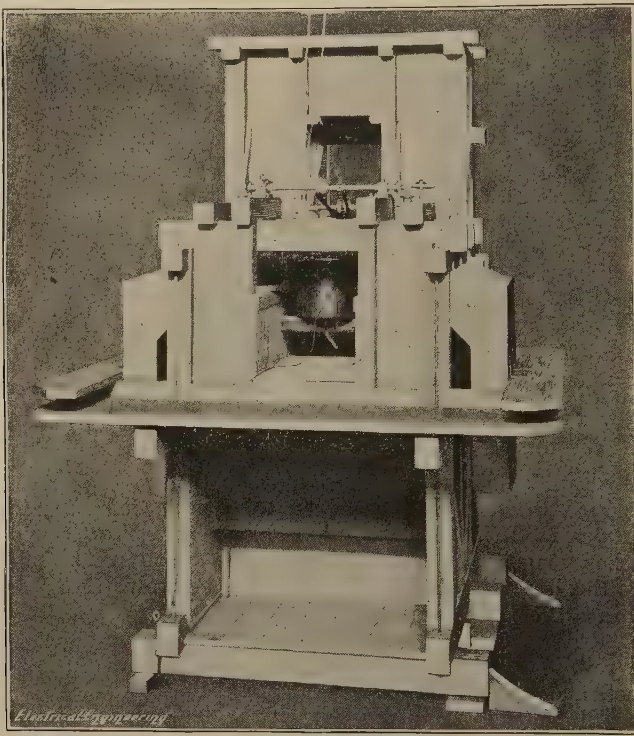


FIG. 153.—Magnetic separator.

A portable electric drilling machine would also be a valuable adjunct to the equipment of a colliery workshop, the drilling of holes being constantly necessary in colliery work.

Electric cranes for general colliery work are also being adopted, and an entirely new departure in the development of electrical application to colliery appliances has lately been patented in the manufacture of an electrically-driven pneumatic hammer.

Electric Welding

Electric welding possesses several advantages over the ordinary methods of welding. It is generally admitted that a weld made by the electric process more nearly approximates to the strength of the solid metal than does a weld made in the ordinary way.

Other advantages are: (1) Awkward breaks, which it is found almost impossible to weld in the ordinary way, can be successfully welded by the electric process; and (2) a break may be repaired on the spot by electric welding, and in non-fiery situations the operation may even be carried out underground with equal ease and satisfaction.

The two systems of electric welding in most general use are the Arc or Benardos system and the Thomson system.

The Arc System

In this system the current is supplied by continuous-current dynamos. It is a low-tension system, the voltage being generally from 80 to 90 volts.

The positive side of the circuit is connected up to the piece of metal to be welded, and on the negative side the cable is attached to a carbon pencil which is supported in an insulated holder. When welding is to be done, the operator holds the carbon pencil at "striking" distance from the point where the weld is to be made, the positive connection having previously been prepared.

In this way an electric arc is formed through the current bridging the air-gap between the point of the carbon pencil and the piece of metal. The resultant temperature is sufficient to enable a perfect weld to be made. A regulating resistance is provided, so that the voltage and amperage can be increased or decreased as the work demands. The unavoidable proximity of the workman to the glare of the arc in this system renders necessary a protecting covering or shade over the eyes and face during the process of welding. Experiments which have been made to ascertain the proportion of strength of an electrically-welded bar to a solid bar have resulted in an efficiency of from 85 to 95 per cent. being obtained.

A modification of the Arc system, known as the Deflected Arc system, has been recently tried. In this modification the cable mains are connected to two carbon terminals, the air-gap between the terminals being adjusted to produce the necessary arc. An electro-magnet situated on one side of the arc deflects or draws out the flame. The electro-magnet is excited by a portion of the current being passed through it.

The principal advantage in this system is that the piece of work to be welded does not form any part of the circuit, thus allowing a

variation in the temperature produced by the arc to be made by simply moving either the carbons or the metal nearer together or farther apart, as the case may be.

The Thomson System

In this system low-tension alternating current is used, and instead of employing a carbon terminal, as in the arc system, the two mains are connected direct to the articles to be welded.

A transformer is included in the circuit, in order to reduce the voltage sufficiently for the welding process.

The current enters the transformer at a pressure of about 200 volts, and leaves it at about $1\frac{1}{2}$ to 2 volts. In this way a heavy current is made to pass through the pieces of metal under treatment, and a great heat thereby obtained. The two pieces of metal are then forced together by mechanical or other means, and the weld made.

CHAPTER XIII

COMPARISON OF THE DIFFERENT MODES OF TRANSMITTING POWER

Steam power—Compressed Air—Transmission by rods—Wire rope transmission —Hydraulic power—Gas and oil transmission—Electric transmission.

The principal advantages claimed for electrical transmission of power, as compared with other systems, are higher efficiency and greater economy in working.

In view of this, it may be advantageous for us to consider briefly the various methods of transmitting the power from surface plant to underground machinery, and to consider the merits and demerits of each individual system, so that we may be all the better able to estimate the position of electrical transmission in relation to the rival systems.

First of all, let us bear in mind that the only primary sources of power usually available at collieries are steam, gas, and oil—water power of sufficient bulk being seldom obtainable for generation purposes.

Electricity, in company with several other modes of power transmission, is therefore only a secondary power, and is dependent for its existence upon the primary sources of power referred to.

The transmission of the power generated in the steam boilers or gas-producer plants may be accomplished either by the direct conveyance of the steam or gas pressure to the point of utilisation, or through the medium of the electric current, compressed air, ropes, rods, or water pressure.

In order to present a satisfactory comparison of those different systems of transmitting power underground let us classify them as follows:—

1. Steam transmission.
2. Compressed air.
3. Rod transmission.
4. Wire ropes.
5. Hydraulic or water power.
6. Gas and oil.
7. Electrical transmission.

Steam Transmission

For nearly half a century the transmission of the steam generated in the boilers through pipes down the shaft and into the underground workings of the mine has been the general practice at the majority of collieries.

This mode of transmitting the power direct is probably cheaper in first cost than any other system, and has the additional advantage of being simple in principle and in application.

There are, however, several notable objections to the conveyance of steam into the underground workings of mines, and the following are the most important of those:—

(*a*) *Loss through Condensation.*—In passing through a length of pipes steam gradually falls in temperature, owing to the cooling effect of the pipes and the resultant radiation of the heat from them. The loss of heat by radiation may, to a great extent, be reduced by covering the pipes with some non-conducting material, and this is generally done in the majority of cases. Still, even when the pipes are coated in this manner, a considerable percentage of loss results from condensation.

The percentage of loss from this cause depends (1) upon the diameter of the pipes conveying the steam, (2) the distance to which the steam is carried, and (3) the amount of power transmitted.

The loss of power increases directly as the length of the pipes. Thus there will be twice as much loss from condensation in transmitting steam a distance of one mile as there would be if the distance were only half-a-mile—the initial pressure and the diameter of the pipes being the same in each case.

A distance of one mile is usually taken as the maximum to which steam can be economically conveyed. The loss also increases directly with the diameter of the pipes, but in estimating the relative loss of power from condensation in different sizes of pipes, another factor must be taken into serious consideration, namely, the frictional resistance to the passage of steam through the pipes.

As the diameter of the pipe increases, the percentage of loss due to friction decreases considerably, and the reduction in the loss due to friction will far outweigh the loss resulting from the greater cooling surface of the larger pipe.

For example, if we take the case of a 3 inch steam pipe as compared with a 6 inch pipe, it will be found that the larger pipe will be able to conduct five times the quantity of steam that the smaller pipe can for the same frictional loss.

Therefore, although the larger pipe would have twice the cooling effect of the smaller, yet the total loss from friction and heat radiation in the 6 inch pipe would only be two-fifths of what it was in the smaller pipe, other conditions being the same in each case. From

the foregoing example it will be readily understood that the most economical results, in the transmission of steam through pipes, is obtained from the employment of large powers. Another factor which influences, to a large extent, the proportion of the power lost from condensation is intermittency of working.

When steam is kept flowing steadily and constantly through a pipe the temperature of the pipe remains practically uniform, and the loss of power due to the cooling effect of the pipe is thus also uniform and minimum.

But, on the other hand, when intermittent working is the daily practice, the pipes, at each recurrent stoppage in the flow of the steam, continue to radiate heat, and the temperature of the steam falls much more rapidly than it would do if it were kept in motion. This, of course, means loss of power, and the longer the period that the "dead" steam is allowed to remain in the pipes the greater will be the loss from this cause.

(*b*) *Other Objections to Steam Underground.*—The employment of steam underground has associated with it several other minor objections. None of these, however, are of so much importance as the economical consideration we have already discussed, and it will be sufficient to briefly enumerate them as follows:—

1. Obstruction of the shaft by the pipes conveying the steam.
2. Danger of the bursting of a pipe or the blowing of a joint.
3. Discomfort and inconvenience, both in the shaft and in the workings, resulting from the continual noise and presence of escaping steam.
4. Increase in the temperature of the mine atmosphere, adding to the discomfort of the workers.
5. Considerable difficulty is sometimes experienced in dealing with the exhaust steam, especially if the engine is situated a long distance into the workings.

Compressed Air

Compressed air, although a secondary power, is largely employed as a means of transmitting the power from the steam-engine into the underground workings of the mine.

It forms a very convenient mode of power transmission, and can be applied to work almost every kind of underground colliery machinery. It is conveyed in pipes after the same manner as steam.

The most important objection to the use of compressed air in the transmission of power is the low efficiency obtained—from 35 to 45 per cent. being its average value. There are, however, some advantages possessed by compressed air which help to counteract the stigma of low efficiency.

For instance, an escape of air from the air-pipes, instead of being a source of discomfort and danger, as in the case of an escape of steam, is beneficial to the ventilation of the mine, although, of course, in both cases a loss of power results. This advantage of aiding the ventilation is especially beneficial in the driving of narrow places, where the atmosphere is frequently far from being pure. In these places the exhaust air from rock drilling machines or coal-cutters helps to purify the atmosphere and improve the ventilation.

Compressed air is also a very safe source of power, and may be employed with equal safety in fiery as in non-fiery mines.

Where compressed air is adopted for transmission purposes, additional expenditure is entailed above and beyond that required where the steam is transmitted direct. The cost of the different air-engines employed underground may, of course, be taken to be about equal to a like number of steam-engines of equal power, but then there remains the extra cost of the air-compressing engine on the surface, and this represents a very considerable figure.

The working expenses of an air-compressing plant, however, compare very favourably with the cost of working the ordinary steam-engine, and the convenience and immunity from the dangers and discomforts which are associated with the presence of steam in underground workings accentuate the superiority of compressed air over steam for transmission purposes. As has been remarked, the efficiency of compressed air as a motive-power is very low, and the following are the principal causes of the large percentage of loss occurring in transmitting the power :—

1. *Heating during Compression.*—During the process of compressing the air in the cylinder great heat is generated, and the air, as the result of its rise in temperature, attempts to expand in volume, obeying the well-known law propounded by Charles which says that the volume of a gas increases or decreases with its temperature. Now, this attempt on the part of the air to expand within a confined space, instead of resulting in an increase of volume, becomes a proportionate rise in pressure, and the increase in pressure simply means that the resistance to the air-compressing engine is correspondingly increased. This increased resistance represents a dead loss of power, and for this reason, and also because compression to high pressures would be impossible because of the high resultant temperature, cooling processes have to be employed to keep the temperature within workable limits.

The cooling of an air-compressing cylinder is variously effected by means of water-jacketing, spraying water into the interior of the cylinder, reducing the temperature of the air to zero before being compressed, and other more or less efficient processes. The speed of an air-compressing engine should be as high as is compatible with safe working, because the higher the speed the less time is allowed

for the heating of the air entering the cylinder and the leakage past valves, and the piston is reduced to a minimum.

Low pressures are more economical than high pressures, for this reason, that the higher the pressure the greater will be the increase in the temperature of the air during compression; consequently the greater will be the resistance to the compressing piston, and the greater the resultant loss of power. Probably the best results are obtained by compressing the air in one cylinder to, say, two atmospheres (30 lbs.), then passing the air through an inter-cooler, there reducing its temperature to that of the atmosphere, and afterwards raising its pressure to say eight atmospheres (120 lbs.) in another cylinder.

Efficiency may also be increased by re-heating the air before it enters the air-motors, enabling freer expansion of the air to take place in the motor. The latest development in connection with the use of compressed air as a motive-power is a combination of electrical and compressed air transmission. Independent air-compressors worked by electric motors may be stationed almost any distance into the workings, and employed to work coal-cutters, rock-drills, and the like. The principal advantage of such a system is that, the compressed air having to be conveyed only a comparatively short distance, there is less loss of power than where the power has to be transmitted from a surface plant.

2. *Loss by Clearance.*—If the clearance space in an air-compressor cylinder is large, considerable loss results, because the air remaining in the cylinder after the compressing stroke of the piston is completed, being at a very high pressure, expands on the back stroke of the piston, and partially fills the cylinder, thus preventing to some extent the entry of air from the atmosphere. To reduce this loss to a minimum the clearance space should be as small as possible.

3. *Frictional Losses.*—Losses due to friction occur during the passage of the air from the compressor to the air motor.

This loss occurs principally in the air-pipes, and as the friction decreases as the diameter of the pipes increases, they should be as large as can be conveniently employed. A very small increase in the diameter of the pipes means a very large reduction in the loss due to friction.

The greatest source of loss in air-compression is that due to heat, the percentage of loss, even with the most efficient cooling apparatus, amounting to about 20 per cent. of the power expended. The loss due to friction is also very large, often amounting to from 15 to 25 per cent.

As the result of those and other sources of loss, the efficiency of compressed air cannot be expected to attain a higher figure than about 45 per cent.

Transmission by Means of Rods

Power has sometimes been transmitted for long distances by means of a combination of rods and oscillating levers. The levers are pivoted vertically on their axles, and a backward and forward movement is transmitted from the crank of a steam-engine through the rods which are arranged to form connecting links between the levers. Power has also been transmitted by means of rods down a shaft and along the underground roadways. Bell-crank levers are used to turn corners. Rod transmission of power is very efficient in some instances, as in the case of shaft pumping, but its use is very limited, owing to the ponderous nature of the apparatus when of great length, and the unsuitability of the reciprocating motion for any purpose beyond the pumping of water.

Wire Rope Transmission

The transmission of power can be very efficiently performed by means of wire ropes. The ropes may be used after the manner of belts for transmitting the power from a steam-engine to different kinds of machinery in and about the colliery, or they may be used, as in the case of underground or surface haulage, as a medium through which the engine may directly perform the work in hand.

In the first case, the rope only transmits the power to secondary plant, while, in the second case, the rope on the drum of the engine is the same rope that performs the work to be done.

In rope transmission the engine may be situated either on the surface or underground. If underground, of course, the steam has to be conveyed to the engine below, and as steam transmission is less economical the most efficient results are obtained by transmitting the power from a steam-engine on the surface down the shaft and into the workings solely by means of the wire ropes.

Wire rope transmission is very cheap in first cost, but the cost of maintaining and renewing the ropes often runs to a high figure.

For instance, perhaps the most efficient system of endless rope haulage is that in which the power is transmitted from a steam-engine on the surface down the shaft to a drum or drums at the head of the engine plane by means of an endless rope, usually known as a band rope. The endless rope proper runs on another drum on the same shaft as the band rope drum. With this method of rope transmission there is practically no loss of power save in the friction of the rope on the various guide and angle-pulleys. A serious disadvantage, however, exists in the very short life of the band rope, and the consequent outlay for frequent renewals.

Another disadvantage of wire rope transmission is the space occupied in the shaft by the ropes, and the necessity for enclosing the ropes in boxes.

Hydraulic Power

This system of power transmission is very limited in its application to mining operations. Perhaps the only class of work to which it can be successfully applied is the pumping of water. It has also been applied to work power rams and movable landings, such as Fowler's well-known apparatus for loading and unloading triple-decked cages, and also in certain inventions for the automatic prevention of overwinding. Perhaps the best-known example of hydraulic transmission of power may be seen in the working of Moore's hydraulic pump, in which two independent columns of water are the medium through which the power of the steam-engine on the surface is transmitted to the pump below. By reason principally of its limited application, hydraulic transmission of power is not in very general use.

Gas and Oil

Gas, as a source of power, has many advantages, and the gas-engine for electric generation purposes bids fair to rival even the most improved types of steam-engine in the near future. The gas may be produced very cheaply, and can be transmitted almost any distance in pipes with very little loss.

It is unsuitable for transmission into mines, however, owing principally to the explosive nature of the vapour and the poisonous and dangerous nature of the exhaust gases expelled from the gas-engine.

Oil-engines are also now being used at many collieries.

Oil is a very cheap and convenient source of power. It can be taken into the mine in tanks or casks to wherever the oil-engine is situated, and so very little trouble and practically no loss at all is occasioned in its transmission underground.

An oil-engine should never be used in situations where the exhaust gases will be carried to working places by the ventilating current. It should always exhaust into the return air-way, so that the gases may be carried straight to the upcast shaft.

One very important objection to the introduction of the oil engine underground is the necessity for a large oil or other flame to heat the vaporiser whenever it is required to start the engine.

Both oil and gas-engines are troublesome to start, and for this reason are unsuitable for many kinds of underground work. For work on the surface both the oil-engine and the gas-engine can be run very economically.

Electrical Transmission of Power

The transmission of power by means of the electric current has many points in its favour, and is now generally considered to be superior in many respects to any other mode of power transmission. For certain classes of work, such as the working of main haulages situated at no great distance from the shaft bottom, it cannot be said to be superior to wire rope transmission, which is probably the ideal system for such work; but for the operation of isolated haulage plants situated a considerable distance into the workings, and as the motive-power for pumping, etc., electricity possesses conspicuous advantages over wire rope transmission.

Moreover, it is a much more flexible mode of transmitting power, and is considerably wider in its application. Electricity is also superior to steam for transmission purposes, and is gradually superseding the latter power in many underground operations where previously that source of power has held supreme sway.

It is in comparison with compressed air transmission, however, that electricity is most severely put to the test. Both sources of power are equally elastic in their application to the various classes of mining work, although, be it said, electricity can be more easily and efficiently distributed to the various points of utilisation. Electricity, however, is much superior to compressed air (except where re-heating is adopted) in efficiency of transmission. The percentage of the power put into the electric generator that may reasonably be expected to be found in brake-horse-power on the motor shaft is from 75 to 85 per cent., whereas in the most efficient compressed air installations (with no re-heating of the air) the percentage of efficiency seldom averages more than about 40 per cent., and with re-heating from 55 to 60 per cent. Another advantage possessed by electricity over compressed air, is that the electric conductor can be more expeditiously and conveniently taken down the shaft and along the roadways of a mine than can the pipes necessary in air transmission, and, in addition, where the electric cables can be suspended, there is less liability of their being damaged or deranged, by upheavals of the floor of the seam or subsidence of the roof, than there is in the case of compressed air pipes.

Against the above advantages, however, it must be remembered that the cost of electric conductors or cables is much greater than the cost of compressed air pipes. Again, it should be noted that electricity in any mine, but especially in a fiery mine, is a source of danger both to person and to property, whereas with compressed air there is very little risk of damage to either in any situation.

For operating coal-cutting machines there is little advantage on either side, the slightly higher efficiency of the electric motor for such work being compensated for by the greater cost of the

electrically-driven machine, and the increased danger in fiery situations. For the operation of rock-drills too, the compressed air machine is superior to the electrically-driven appliance as at present constructed, although, be it remarked, there is likely to be great developments, both in principle and in design, in electric rock-drills in the near future.

Even with the important disadvantages which, from the foregoing remarks, it will be seen that electricity possesses in comparison with compressed air, no mining engineer of any standing would advocate the putting down of a compressed air plant in preference to an electrical installation, save, it may be, in very fiery mines.

CHAPTER XIV

DANGERS OCCURRING FROM THE USE OF ELECTRICITY IN COLLIERIES

Principal causes of accidents—Ignorance and carelessness—Training of attendants—Defective apparatus—Systematic inspection of cables, plant, etc.—Effects produced by electric shock—Dangers of high-pressure current—Resistance of the human body—Treatment for electric shock—Sylvester's method of resuscitation—Dangers from fire—Dangers of electricity in fiery mines—Gas-tight motors—Dangers of sparking at the face.

No one will attempt to deny that many grave dangers are associated with the use of electricity both on the surface and under. Nevertheless, with ordinary caution and a thorough appreciation of the nature of the dangers to be guarded against, there need be no more risk run in attending electrical machinery than there is in the care of steam-engines and boilers.

Obviously the first precaution that must occur to one, whereby the dangers resulting from the employment of electricity may be considerably minimised is the education of all attendants of electrical apparatus into a thorough understanding of the functions of the different electrical apparatus under their charge, and combined therewith a clear grasp of the fundamental principles governing the behaviour of electric currents.

In the production, transmission, and use of electricity, as in other phases of human activity, probably more accidents can be traced to ignorance on the part of electrical attendants than to any other cause, and we make bold to say that no workman ought to have the care and control of electrical apparatus imposed upon him without first being trained in the elementary principles of electrical science, and duly impressed with the hazardous nature of the work and the necessity for extreme caution and watchfulness.

The possession of a complete knowledge of those materials which form electrical conductors and those which form insulators, is undoubtedly a very valuable acquisition to those coming daily into contact with electrical apparatus, and such men would do well to commit to memory a list of conductors and insulators such as that given in Chapter I. of the present volume.

In the Special Rules for the Installation and Use of Electricity at Collieries we have an excellent compendium of rules and precautions which, if rigorously observed, will certainly go a very long way in the prevention of accidents due to the use of the electric current.

But the question arises, Does electrical apparatus at collieries always come up to the standard required by the Special Rules? Too often, it is to be feared, the employment of paltry and altogether inadequate "makeshifts" takes the place of what should be reliable and electrically-safe appliances. Unquestionably such "makeshifts" cannot be too strongly condemned, and many accidents may be traced to this cause alone. Then, again, is it not often the case that defects in cables, switches, and other electrical apparatus at collieries are allowed to exist far beyond the length of time really necessary for the repair of the faults and deficiencies?

The defects may be known to the management, but are not considered sufficiently glaring to demand immediate attention, and so they are allowed to remain, to the extreme danger, it may be, of workmen and attendants.

Such ignorant or wilful neglect is most reprehensible, and is altogether unworthy of a thoroughly capable manager of a colliery where electricity is employed.

If the management is a capable one, prompt attention should be paid to all defects, however slight, in electric apparatus, as not only will risk to human life be averted by such a course of action, but the life of the property will be prolonged and the safety of the mine maintained.

Periodic and systematic inspection should be made of all cables, joint boxes, connections, etc., so that no defect may remain undetected, and when defects occur they should be promptly put right.

All cables should be of ample current capacity for the requirements of the installation, and the insulation should be heavy and of the very best material.

Switchboards should, of course, be of insulating and uninflammable material, and should be of sufficient size to accommodate the meters, switches, fuses, etc., without any approach to overcrowding.

Switches should be of the latest improved description, fuses either entirely enclosed or embedded in porcelain handles, and all other apparatus of similar up-to-date description.

Still, however, even with the most perfect appliances and the most extreme caution and care on the part of those brought daily into contact with electrical apparatus, we can hardly expect that accidents from electric shock will be entirely eliminated, and a brief outline of the course of action to adopt in the event of such an accident occurring may be found of great utility.

The effects produced by a charge of electricity, if such charge

be sufficient, are complete stoppage of the breathing, and stagnation, or rather suspension, of the heart's action.

The voltage necessary to produce electric shock in a human being can hardly be limited to any specified pressure, as it depends upon (1) the conductivity of the person's body, and (2) the amount of surface in contact.

For instance, one case is recorded of a person being killed by so low a pressure as 95 volts. The current was alternating, and the victim was of weak constitution. Another circumstance which lowered the resistance to the passage of the electric current to earth, by way of the victim's body, lay in the fact that he was working with bare feet on wet ground. In another case a man was killed at a pressure of 200 volts, by taking hold of a bracket with both hands. In this case the heart lay in the direct course of the current. On the other hand, persons have been known to survive shocks at pressures of as much as 3300 volts, and even 5000 volts. Undoubtedly, however, the risk of shock with low pressures is small compared with the risks attached to the use of high-pressure current. There is more danger, too, with alternating current than there is with continuous current.

Properly speaking, it is not correct to say that a person was killed *by* a certain pressure, because it is not the voltage but the *amperes* that kill, although, of course, the amount of current that will pass through the body is determined by the voltage and the resistance of the surface in contact.

The resistance of the human body is given at values varying from 1000 to 2000 ohms.

The latter figure may be taken as representing the average resistance of a vigorous and healthy frame, and the former as the resistance of a system weak in heart action, and delicate in build.

The amount of current that will cause death is stated by various authorities at from $\frac{1}{10}$th to $\frac{1}{2}$ of an ampere.

For the purpose of practical illustration, suppose we take the case of a healthy person with a resistance to the passage of electricity of 2000 ohms, and a current of electricity at a pressure of 500 volts passes through his body. The amperes will be found thus :—

$$\frac{E}{R} = C \text{ or } \frac{\text{volts}}{\text{ohms}} = \text{amperes};$$

$$\therefore \frac{500}{2000} = \tfrac{1}{4}\text{th of an ampere,}$$

which would produce insensibility, and probably death, if prompt action were not taken and resuscitation attempted.

The resistance of 2000 ohms would require a good surface contact, about 10 square inches, so that if the contact were less than this the resistance would be greater and the amperes less.

A moist skin will also enable the current to pass more easily than would a dry one.

Something also depends upon whether the heart lies in the direct line of the current or not.

For instance, a current passing from the hand to the head is not so dangerous as a current passing from hand to hand, because, in the latter case, the current must pass straight through the heart.

Care should therefore be taken in working amongst electrical apparatus when the current is on to work with only one hand at a time, where that is possible, and let it be always the right hand.

It must also be remembered, of course, that in accordance with the Electric Rules "no repair or cleaning of the live parts of any electrical apparatus, except mere wiping and oiling, shall be done when the current is on," and that "gloves, mats, or shoes of india-rubber or other non-conducting material shall be supplied and used where the live parts of switches or machines, working at a pressure exceeding the limits of low pressure, have to be handled for the purpose of adjustment."

Treatment for Electric Shock

If the vital tissues of the body are not destroyed, it is possible to recover.

In rescuing a person in contact with electric conductors, the following course of action should be taken *at once.*

1. Break or disconnect the circuit, if that be practicable.

2. Remove the body away from contact with the wire, cable, or other conductor.

In doing this, care should be taken to stand on some insulating substance, such as a rubber mat, piece of dry wood, an article of clothing, and the like, and the body should be seized by the clothing and *not by the flesh.*

3. Send for a medical man.

It cannot be too strongly urged that promptness and a cool head are essential in such crises.

When the victim of shock has been removed from contact with the "live" metal, he should be placed flat on his back, if possible in a slightly inclined position. A roll of cloth or other similar material should next be placed under the shoulders, and artificial respiration proceeded with without delay.

Sylvester's Method of Resuscitation, as recommended by the Royal Humane Society, is the one generally adopted. The *modus operandi* is as follows: The first thing to do is to remove all tight clothing from about the neck and chest—everything, in fact, covering the body above the waist. This is essential for the effective carrying out of the movements necessary in the process of resuscitation. Next draw

forward the patient's tongue to its full extent, and secure it in that position by means of an elastic band or piece of tape or ribbon over the tongue and under the chin. This allows the air free access to and from the lungs while artificial respiration is being performed.

If the body is now placed in the reclining position already indicated, an attempt at the restoration of life may be proceeded with.

It should be always borne in mind, of course, that the above preliminaries should occupy as short a time as possible. In such crises time is very precious, and even a second lost through delay or blundering of any kind lessens the chances of the victim's life being saved.

Everything being in readiness, the person who is to carry out the respiratory process stands at the victim's head, and, grasping the arms immediately above the elbows, raises them gently and steadily upwards over the head, keeping them in this position for about two seconds. By this means the chest is raised, the lungs expanded, and air is drawn in, or inhaled.

He then lowers the arms and presses them gently but firmly against the sides of the chest. By this means the lungs are made to contract, and air is expelled from them.

These movements should be repeated, as far as possible, at a uniform rate, so as to alternately expand and contract the lungs once every four seconds, this being equivalent to fifteen respirations per minute, which is the average in natural breathing.

Artificial respiration should be continued till spontaneous attempts at breathing are noticed, and should never be discontinued, though seemingly unavailing, till at least three hours have elapsed since a start was made. Further, there must be no cessation, however brief, in the work of resuscitation, as this would be fatal to the success of the effort.

The upward and downward movements must be steadily performed fifteen times in every minute, during the whole time.

When the first operator has become exhausted, another must be ready to take his place, and carry on the work of respiration without the missing of a single breath.

After breathing has been restored, efforts should be at once directed to the promotion of the circulation, and the restoration of warmth in the body.

The limbs should be rubbed upwards, *i.e.* towards the heart, flannel or other soft clothing being employed for the purpose. Warm flannels, bottles, and the like should be applied to various parts of the body, especially the region of the stomach, and the judicious administration of small quantities of warm water or coffee when the patient is able to swallow will materially help towards recovery.

The injection of ether and alcohol under the skin, through the medium of a fine hollow needle, having a small syringe attached, has

also been advocated as an aid to the restoration of life after electric shock. The raising of the lower limbs and the body, and the administration of a few smart blows on the body over the heart may also be effectual in re-animating the vital organ.

Dangers from Fire

The occurrence of a fire in the underground workings of a mine is, indeed, a terrible thing, especially if the blaze catches hold of the solid coal. Sometimes such a fire may assume enormous dimensions, and, it may be, ultimately cause the abandonment of the entire mine. But a fire may not only cause considerable loss of property, it may also cause the loss of valuable human lives. Many a life has been lost in the attempt to fight the ravages of an underground fire, some through the fumes and smoke, some from the deadly carbon monoxide emitted from the fire when in a smouldering state, and some even from the consuming flames of the gigantic conflagration. Now, there are many ways in which the electric current may be the direct cause of the commencement of a fire. The breaking of a live cable, the blowing of a fuse, the heat given off from lamps, short-circuiting, and the like, may very well inaugurate disastrous fires, did no one know of the occurrence. In view of this, effective precautions must be taken at every point where there is any possibility of the electric current causing a fire, should any fault or defect occur in the apparatus.

Let us commence at the generator-house, and go right from where the current is generated to the point of utilisation, and see what can be done to eliminate the possibility of a fire taking place.

The Generator-House

The house or power station, in which are situated the machines for the building up of electrical energy, should always be, as far as possible, of fireproof construction, and situated entirely apart from all structures of wood or other inflammable material. By this precaution the outbreak of a fire in the generator-house will be effectually prevented from spreading to the woodwork of the pit-bank, to timber heaps, or to other engine-houses in and about the colliery.

Fire buckets, filled with clean, dry sand, should also be kept in a handy position, in all power stations or generator-houses, as well as all motor-rooms both above and below-ground, so as to be ready for immediate use in extinguishing fires.

This precaution is strictly enjoined by the Special Rules for the Installation and Use of Electricity, and must, therefore, be complied with.

Cables

A fire may be caused by a cable or conductor breaking, or, as is more frequently the case, a short-circuit, or fault, occurring in either one cable or in the other.

It should be borne in mind, however, that a short-circuit can only take place if the two conductors are connected with earth at the same time.

Various circumstances may arise, however, which would bring about such a situation. For instance, in one cable the insulation may be destroyed through some accident, and the conductors connected to earth, and in the other, though the insulation may not be broken up or destroyed, it may yet be so soaked with water that a good connection to earth is made, and in this way short-circuiting may occur. Again, a damp situation may alone cause a "short" in the cables, as, if the insulation of each conductor becomes soaked with water, a short-circuit must inevitably follow. Fortunately, situations where such conditions prevail do not favour the outbreak of a general conflagration.

A short-circuit occurring at any point in a circuit, however, where highly inflammable material, such as dry wood, dry coal dust, brattice-cloth, and such like, are in near proximity to the fault, may very well result in an outbreak of fire.

Some kinds of cable coating and covering are highly inflammable, as, for instance, tape and braiding, and should a short-circuit take place this stuff may take fire. The flame from a short-circuit does not require to be of long duration in order to start a fire. In a deep mine a high temperature is often unavoidable, and the dry state of everything renders the production of a fire a very much easier process than it would be under less favourable circumstances.

Wire-armouring on a cable will tend to prevent the burning of inflammable coverings, such as tape and braid, when a short-circuit occurs, as, being efficiently earthed, the armouring would conduct the leakage to earth with a minimum risk of injury or accident.

On the other hand, armouring of cables makes a fault or "short" more likely to occur, as there is only the insulation of the cable between the copper conductors and the armouring; a fault is also more difficult to detect and locate when the cables are armoured.

The different types of cables, and the various methods of laying, fixing, and jointing them, in order to prevent injury or deterioration of the insulation, will be found fully discussed in Chapter III., where the methods of locating a fault and testing the insulation are also treated.

Fuses and Cut-Outs

The "blowing" of a fuse may very readily cause a fire, if there is any inflammable material near. Fuses are, however, generally carried on the switchboard, and, as that must be of uninflammable material, the only things that could catch fire in the case of the burning of a fuse would be the framework (if that be of wood) supporting the switchboard, or any inflammable stuff that might, perchance, be lying near at the moment. Fuses are sometimes enclosed in air-tight iron cases, and in mines where General Rule No. 8 of the Coal Mines Regulation Act applies, this precaution is now compulsory. Circuit-breakers and cut-outs should also be enclosed in iron cases, or break under oil.

Motors and Motor-Houses

Motor-houses have as much, if not more, need to be constructed of fireproof material as the power station on the surface.

The motors should be placed, as far as is practicable, on brick or concrete foundations, and the motor-house walled around with brick and lime. The roof should be of sheet-iron carried on iron rails or girders.

All stationary motors using current above the limits of low pressure must, of course, be earthed according to the Special Rules, so that when a short-circuit or fault occurs, the leakage in certain circumstances may be conducted straight to earth. Care should be taken not to flood the motor bearings with oil to such an extent that there is any possibility of the oil finding its way to the electrical parts of the machine.

Particular care should be taken not to allow any oil to get on the commutator, as the sparking at the brushes would readily ignite the oil and, it may be, cause considerable injury to the motor.

Heat given off by Incandescent Lamps

The incandescent lamp gives off great heat when burning. This can be forcibly demonstrated at any time by touching the glass bulb with the hand after the lamp has been burning for some time. It has been estimated that about 90 per cent. of the energy absorbed in a filament lamp is expended in the generation of heat. If the glass bulb of an incandescent lamp be in contact with any very inflammable material, such as dry coal dust, cotton waste, hemp yarn, or dry wood, it is quite possible that a fire may result.

All filament lamps should therefore be placed in situations where they cannot come into contact with inflammable material of any description, and where the air-current can have free access to them so as to readily dissipate the heat.

Dangers of Electricity in Fiery Mines

In addition to the many dangers from fire and shock which may be said to be inseparably associated with the use of electricity in any circumstance, there is also considerable risk attached to its introduction into fiery mines.

In seams giving off much fire-damp there remains the possibility, at any moment, of gas accumulating in dangerous quantities, and, no matter how efficient may be the ventilation, it is practically impossible to avoid the existence of a highly explosive mixture at some time or other.

Now, although an electric spark may quite safely occur in non-fiery situations, or in an atmosphere which, though gaseous, yet contains an insufficient quantity of gas to make the mixture explosive, such a spark occurring in an air-current containing the necessary percentage of explosive gas would most certainly be sufficient to ignite the mixture.

Of course, as a general rule it is not often that in a well-regulated mine the percentage of gas in the air-current is allowed to attain dangerous proportions. Still, such contingencies may and do occur, and, knowing full well the extreme peril and danger both to life and property when such conditions prevail, it is well that we should have a due appreciation of the risks run in the introduction of electricity into mines where there is the least chance of dangerous accumulations of fire-damp, and the precautions which must be taken to combat the danger.

First of all, it will be well if we for a moment consider what constitutes an explosive mixture in a mine.

A mixture of fire-damp and air, according to the generally accepted standard, will not explode until there is 1 part of the former to 13 of the latter, which is equivalent to an atmosphere containing about 7 per cent. of fire-damp; and even in that proportion the mixture will explode but feebly.

The highest explosive point is reached when there is from 10 to 12 per cent. of gas present, the mixture then being made up of 1 part of CH_4 to from 9 to $7\frac{1}{2}$ parts of air. As the percentage of fire-damp increases above this point the explosibility of the mixture *decreases*, until when there is about 20 per cent. of the gas present an explosion will not occur if a light be applied.

There is, however, another important circumstance which must be taken into consideration in discussing the explosibility of a mixture of fire-damp and air. In many present-day mines the presence of dry coal dust, in a finely subdivided state floating in the air, makes extremely dangerous an atmosphere which but for that would be perfectly safe.

This fine coal dust, if present in sufficient quantities, will render an

atmosphere explosive with the addition of less than even so small a quantity as 2 per cent. of fire-damp.

Now this amount of fire-damp may often be present in the air-current, as when "blowers" of gas occur, and, in consequence, in dry and dusty situations the atmosphere must be considered explosive and dangerous when so much as 2 per cent. of gas is detected.

The great difficulty, in such circumstances, is that the ordinary safety-lamp will not detect less than 2 per cent. of fire-damp, so that the only safe course is to have some more sensitive apparatus for the purpose.

Let us now consider the various points in an underground electrical installation where sparking may occur, and the precautions to be taken in each case.

Sparking at Switches

In open-type switches sparking very often occurs when the current is switched on and off, and this sparking is liable to take place with either continuous or alternating current. In non-fiery situations this is of little consequence, but if fire-damp were present it would probably prove disastrous. In fiery situations, however, the switches are either enclosed in a strong gas-tight box or break under oil. Both of these types of switches are described in Chapter III.

Sparking at Brushes

Sparking at the brushes of a continuous current motor may result from various causes, of which the following are a few :—

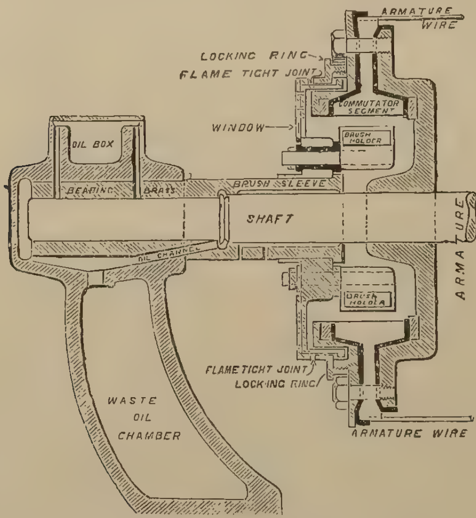
1. Insufficient contact surface between brushes and commutator.
2. Incorrect or faulty alignment of the brushes on the commutator.
3. Excess of load.
4. Variation in the precise position of the neutral point.
5. Dust on the commutator.

When the motor attendant notices the brushes sparking he should first of all see that they are set exactly in line. If the brushes do not seem to be lying properly they should be taken off singly and trimmed or ground down to the exact curvature of the commutator. This must, of course, only be done when the motor is standing and the switches drawn. The variation of the neutral point may be counteracted by rocking each set of brushes a little way in either direction round the commutator until sparking stops. The commutator may be kept clean by the frequent application of glass-paper. The commutator should also now and then be thoroughly cleaned with a piece of clean cloth. A slight touch of vaseline should also be sometimes applied. Even with the greatest care

and watchfulness, however, sparking cannot fail to occur sometimes with an unenclosed continuous current motor.

Gas-tight Motors are now manufactured for use in fiery mines. In these the motors are enclosed in strong iron or steel casings, strong enough to resist an explosion of gas should that occur in the interior of the casing. In some of these motors there are a number of slotted openings, somewhat equivalent to the gauze in a safety lamp, which are useful in dissipating the heat given off in the motor, and assist in preventing any sparks or flaming from reaching the outside atmosphere. In direct current stationary motors, such as those for

(DAVIS & STOKES PATENT.)



SECTION OF SAFETY COMMUTATOR.

FIG. 154.—Safety commutator for gassy mines.

working haulage and pumping plants, what are known as safety commutators are used. A good type of safety commutator is shown in section in Fig. 154.

The idea of the safety commutator is to enable direct current motors to be employed in fiery mines, and to obviate the danger of sparking at the brushes, which might cause the ignition of gas. From the illustration it will be seen that the safety commutator differs from the ordinary form in having the brush contact on the inside of the commutator segments instead of on the outside. The segments of the commutator are clamped between a ring and a specially designed disc which is keyed on the shaft. The brush

holders and brushes are carried on a disc sliding on the extended brass bearing, and the brushes can be set in their proper position by means of a clamping handle. Any sparking at the brushes can be noted through small windows set in the disc, and so corrected.

Burning out of Fuses

The "blowing" or burning out of a fuse results in a momentary flash of flame of considerable magnitude, which could not fail to fire gas if it were present at the moment in sufficient quantity. Open type fuses are, however, entirely prohibited in fiery mines by the Electrical Rules, and should never be used in seams which have been known to give off gas at any time.

The fuses should be enclosed in a strong gas-tight iron case or box. The same precaution applies to cut-outs and circuit-breakers.

Dangers of Sparking at the Face

Admittedly there is grave risk attached to the introduction of electricity into a mine liable at any time to dangerous outbursts of explosive gas, and these dangers are increased tenfold when we come to consider the application of the electric current to coal-cutting and drilling machinery at the working face.

It is here that the fire-damp first emerges from the seam and commingles with the air. In a seam giving off much gas the fire-damp is almost continually being emitted, and each new cut or breaking of coal sees fresh supplies of CH_4 freed from *in situ*, and vomited forth into the atmosphere of the mine, to the dread and danger of the workmen.

Now, it will be readily admitted that very careful consideration must be given to all sides of the question before deciding upon the introduction of electrical coal-cutting or drilling machinery into a seam giving off fire-damp.

It should be remembered, however, that in most gassy mines, even at the working face, it is not very often that gas is present in quantity sufficient to render the air explosive, and it would consequently be quite safe to run an electric coal-cutter during the period that the mixture was within a safe distance of the explosive point.

The question is how to be able to determine the explosive point, and to have an accurate indication of the rise and fall of the percentage of gas in the air.

The Special Rules for the Installation and Use of Electricity in Mines enjoins that "a safety lamp or other suitable apparatus for the detection of fire-damp shall be provided with each machine when working, and should any indication of fire-damp appear on the flame of the safety lamp or other apparatus used for the detection of fire-

damp, the person in charge shall immediately stop the machine, cut off the current at the nearest gate-end or switch, and report the matter to an official of the mine."

Now this is all very good, but we have seen that the ordinary safety lamp will not unmistakably indicate a percentage of gas which would render an atmosphere explosive, *if the situation was a very dry and dusty one.*

In a dry and dusty mine, with a coal seam giving off fire-damp even in small quantities, some more delicate and accurate means of detecting fire-damp than the safety lamp has been proved to be must be provided before an electrical coal-cutting machine can be used in a fiery mine with absolute safety.

With such an apparatus in use, an electric coal-cutter may be worked so long as the presence of fire-damp remains unindicated, but once it is detected the motor must be at once shut off, and the current cut off at the nearest gate-end panel or switch-box.

APPENDIX

QUESTIONS SUITABLE FOR STUDENTS PREPARING FOR COLLIERY MANAGERS' EXAMINATIONS.

1. Give a general outline of the various plants necessary for a continuous current electrical installation. If the power has to be transmitted down the shaft and into the workings for a total distance of 1000 yards, and an effective horse-power of 100 is required in the haulage motor, what will the horse-power of the generator require to be?

2. Enumerate the different purposes for which electricity has been applied in collieries.

3. Compare the relative efficiencies of electricity and compressed air. Supposing each to be modern and well-designed plants, what will be the percentage of the power of the steam-generating engines that you would expect to find in (*a*) the electric motor, and (*b*) the compressed air engine? Detail the different sources of loss in each case.

4. Clearly define the four electrical units in common use. What, in your opinion, is the most suitable voltage to use for power, looking at the matter from the standpoint of economy and safety?

Note.—Where the power has to be conveyed for long distances, pressures up to 3000 volts may be very economically employed, the current being afterwards transformed down to a lower voltage before entering the motors. As regards safety, however, probably the best voltage to employ is from 450 to 650 volts.

5. Sketch and describe four types of electrically driven coal-cutters.

6. Electrical energy amounting to 150 horse-power has to be transmitted a distance of one mile from the generator, and is to be employed for haulage purposes. What voltage would you adopt, and what description of dynamo would you instal? What type and horse-power of engine would you adopt? What would be the

size of cables necessary? And how would you carry them down the shaft and along the underground roadways?

7. Under what conditions would you prefer coal-cutting machines to manual labour? State some of the benefits accruing from the employment of coal-cutters.

8. Give a description of the best starting switch with which you are acquainted for controlling a motor of 30 B.H.P.

9. Describe two types of electrically-driven pumps, one coupled direct to the motor and the other worked by gearing.

10. What type of prime mover would you adopt for driving an alternating current generator of 500 kilowatts output? Briefly describe the principle of the Parsons and the De Laval steam turbines.

11. Describe the principle underlying the generation of electricity in the dynamo. How is the current measured, how is the power calculated, and through what medium is it conducted down the shaft and along the roadways of a mine?

12. Give a general outline of the dangers occurring from the employment of electricity underground, and the precautions to be taken in each case.

13. An electric motor is used for driving a three-ram pump underground. When the motor is working at full load the ammeter reading is 65 amperes. If the voltmeter records a pressure of 410 volts, what is the power developed in the motor?

14. What is the relative strength of a welded bar to a solid bar? Describe how electric welding is performed, and state its advantages over the ordinary method.

15. How much additional power would be got by placing one belt upon the top of another? Under what circumstances would you prefer rope drives to belts?

Note.—About 40 per cent. additional power can be obtained by running one belt upon the top of another.

16. Describe two different types of primary cells.

17. Give some advantages of electric signalling. Describe the apparatus required for electric signalling.

18. Sketch and describe the high-tension and the low-tension systems of electric blasting. What are the advantages of shot-firing by electricity?

19. A Waddle fan gives 60,000 cubic feet of air at 2 inches water-gauge. An electric motor is to be substituted for the steam-engine driving the fan. What horse-power of motor would be required? How would the power be applied?

Note.—Horse-power of motor may be found as follows:—

$$\frac{60{,}000 \times 2 \times 5{\cdot}2}{33{,}000} = \text{H.P. in the air.}$$

Then take efficiency of fan to be 0·75, and efficiency of motor and gearing, say, 0·65, and proceed as follows:—

$$\frac{\text{H.P. in the air}}{0{\cdot}75 \times 0{\cdot}65} = \text{Actual H.P. of motor required.}$$

Adopt a motor-speed of, say, 480 revolutions per minute, and then, with the fan running at 80 revolutions per minute, the power may be transmitted from the armature pulley to the driving wheel on the fan shaft by means of a belt, with no gearing whatever. The ratio of the diameters of the motor pulley and the driving wheel would be as 480 is to 80 or as 6 is to 1; that is, if the motor pulley were 1 foot in diameter the driving wheel would be 6 feet.

20. A motor for driving an endless rope haulage gear runs at 630 revolutions per minute. The haulage drum is 6 feet in diameter, and the speed of the rope $2\frac{1}{4}$ miles per hour. State in detail how you would effect the necessary reduction in speed.

Note.—The haulage drum is 6 feet in diameter, and therefore in one revolution the rope travels $6 \times \frac{22}{7} =$ say 19 feet. The speed of the rope per minute is $\frac{2\frac{1}{4} \times 5280}{60} = 198$ feet nearly, so that the drum must revolve $\frac{198}{19} =$ say $10\frac{1}{2}$ times per minute. The speed of the motor being 630, the ratio is $\frac{630}{10{\cdot}5} = 60$ to 1. This reduction may be effected, solely by spur gearing, as follows: Diameter of motor pinion, 1 foot; diameter of first spur wheel, 3 feet; diameter of second pinion, 1 foot; diameter of second spur wheel, 4 feet; diameter of third pinion, 1 foot; diameter of third spur wheel, 5 feet. The first reduction could, however, be satisfactorily made by means of belt drive, if space permit.

21. Suppose you were asked to report upon the efficiency, economy, and safety of electric power as applied to haulage, pumping, and coal-cutting, how would you proceed?

22. Give some of the advantages and disadvantages of electric drills. Give a short description of one of the best of these.

23. Give some account of the system of working an electrical underground coal-conveyor in conjunction with a coal-cutter. On a longwall face of 100 yards in length how many men would you employ, and how much coal would you expect to be able to deal with on the conveyor system?

24. What type of electric cable is most generally adopted for mines? How is it insulated and protected?

25. Give your opinion as to the average cost of producing electricity at a colliery.

26. What are the advantages of electric lighting in collieries? Give a short description of the incandescent and the arc lamps.

27. Describe the insulation test for cables.

28. Describe the Siemens-Ilgner system of electric winding. Has it ever been applied in this country?

29. What are the advantages to be gained in firing shots by electricity? Describe the series and parallel systems of firing shots in groups. Under what circumstances may shots be fired with current taken from lighting or power mains?

30. Give some account of an electric locomotive suitable for working on an underground level plane. Has electric locomotive traction ever been attempted on steep grades? If so, give an account of the system.

31. What are the advantages and disadvantages of electric safety lamps? Describe any form of lamp with which you are acquainted.

32. In what manner do alternating currents differ from continuous? What is your opinion as to the relative advantages of the two systems?

33. Sketch and describe the three types of dynamos or motors, namely, series, shunt, and compound.

34. Define period, frequency, E.M.F., back E.M.F. and Lag and Lead.

35. What determines the resistance of an electric circuit?

36. An electrical installation is to be put down at a certain colliery. The continuous current dynamo is to have an output of 75 kilowatts, and the prime mover is a compound horizontal steam-engine. The distance from the surface generator to the motor underground is 1200 yards. Two single 19/18 cables are used. The cables are bitumen-insulated and armoured. The underground motor is of 60 B.H.P. Give a rough estimate of the probable cost of (*a*) the steam-engine, (*b*) the dynamo, (*c*) the cables, and (*d*) the motor.

If the buildings, concrete foundations, and other masonry work cost a third of the aggregate of the above four items, what will be the total outlay?

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